May 18, 1893.

The LORD KELVIN, D.C.L., LL.D., President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On Some Circumstances under which the Normal State of the Knee Jerk is altered."* By J. S. RISIEN RUSSELL, M.B., M.R.C.P., Assistant Physician to the Metropolitan Hospital. Communicated by Professor VICTOR HORSLEY, F.R.S. Received March 3, 1893.

(From the Pathological Laboratory of University College, London.)

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Introduction.

For the inception of the following work, which it is hoped will add some further facts to our knowledge of the most important of the "deep reflexes," the knee jerk, I am greatly indebted to the very kind suggestions of Dr. Hughlings-Jackson. To him I owe my best thanks for proposing the question of the influence of the asphyxial

* Part of the expenses connected with this experimental investigation have been defrayed by a grant from the Scientific Grants Committee of the British Medical Association.

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state on the knee phenomenon, as a subject likely to be fruitful. The adoption of his early advice led to the investigation of many other points of noteworthy interest. I am also much obliged to Professor Horsley for suggestions, especially with regard to control experiments and operative procedures.

Since Brown-Séquard* described the condition expressed by him under the term spinal epilepsy, the so-called deep or tendon reflexes have attracted considerable attention, and have been the object of numerous investigations.

Charcot and Vulpian† were the first to accurately describe the phenomenon known as ankle clonus.

Bouchard‡ next observed the arm reflexes, and Erb§ and Westphal simultaneously directed their attention to the contraction of the quadriceps extensor which follows percussion of its tendon. Erb looked on the phenomenon as a reflex, while Westphal considered it the result of direct excitation of the muscle percussed or pulled at its extremity.

Joffroy endeavoured to prove that cutaneous excitation often evoked the phenomenon, and this view was not refuted until it was shown that it could be evoked in animals by percussion of the denuded tendon.

Westphal pinched, pricked, and irritated the skin in various ways without producing the knee jerk; a fold of skin lifted away from the tendon and subjected to blows with a hammer was attended with a like negative result. On the other hand, when the skin lying over the ligamentum patellæ was frozen by means of Richardson's process the contraction which followed a blow on the tendon was in no way lessened; nor was it where cutaneous anæsthesia existed in non-tabetic cases.

It soon became evident to observers that the knee jerk is a normal phenomenon, while ankle clonus is only met with in association with abnormal states; but there was some discrepancy of opinion as to whether the knee jerk is always present in healthy subjects. Berger‖ noted its absence in 1·567 per cent. of normal individuals; while in over 200 instances Eulenberger¶ never failed to elicit it in the newly born at various ages, and Gowers** states that it is probably never absent in health.

* 'Journ. de la Physiol.,' vol. 1, p. 475, 1858.

† 'Soc. Méd. des Hôp.,' May, 1866; 'Union Méd.,' p. 464, 1866.

‡ 'Arch. de Méd.,' vol. 2, p. 290, 1866.

§ 'Arch. f. Psych. et Nerven.,' vol. 5, p. 792; *ibid.*, vol. 5, p. 803, 1874; Comptes Rendus et Mém. de la Soc. de Biol.,' Series VI, vol. 2, p. 61, 1875.

‖ 'Centralbl. f. Nervenheilkunde,' 1879.

¶ 'Correspondenz-Blatt f. Schweizer. Aerzte,' Nos. 1 and 2, 1879.

** 'A Manual of Diseases of the Nervous System,' 2nd Ed., vol. 1, p. 431.

Westphal* connected for the first time the absence of the phenomenon with sclerosis of the posterior region of the lumbar cord, and Petitclerc† showed that it is also absent when the anterior roots of the spinal nerves are affected. It was about this time that Buzzard‡ called attention to the fact that in conditions where the knee jerk is absent the response of the vastus internus muscle to direct percussion may be actually more brisk than in health.

Exaltation of the tendon reflexes was recognised by numerous observers as existing where muscular spasm, contracture, and "epileptoid trepidation" are present, and that these conditions are associated with sclerosis of the pyramidal tracts of the spinal cord.

In the investigation of afferent nerves in tendons and such as would form the first part of a reflex loop, Tschiriew§ is generally supposed to be the first observer who discovered nerve fibres, without myeline, which terminate in the aponeuroses in the neighbourhood of tendons, which he looked on as the organs of transmission of the muscular sense. These centripetal nerves had, however, previously been noticed, but imperfectly described, by Sachs. And Golgi‖ and his pupil Cattaneo¶ fully described the nerve endings in tendons; and, although Golgi's completed work did not appear until 1880, his first publication on the subject was three years prior to this.

Nothnagel** found that when clonus existed it could be arrested instantly by pressure on the anterior crural or sciatic nerve, and that pressure on the former nerve stopped the movements in the territory of the sciatic as well as in its own, and that pressure on the nerves of one side puts an end to the phenomenon on the opposite side. Lewinski†† further showed that in cases of contracture with exalted reflexes increase of the tendon of the tension of the contracted muscle, however brought about, would evoke clonus, as would excitation of the nerve supplying the muscle with a moderate induced current; while cutaneous stimulation by pinching the skin, or by squeezing the toes or fingers, would arrest it, as would excitation of the nerve supplying the muscle with a strong induced current. If the tendon was first rendered lax, none of the methods which formerly evoked the clonus would do so.

* 'Arch. f. Psych.,' vol. 8, p. 514.

† "Des Réflexes tendineux," 'Thèses de Paris,' 1880.

‡ 'Lancet,' July, 1878.

§ 'Arch. d. Physiol.,' Series II, vol. 6, p. 89, 1879.

‖ 'Rendiconti del Reale Istituto Lombardo,' fasc. IX, p. 445; 'Gaz. Lomb.,' vol. 7, s. V, p. 23; 'Atti d. Soc. Ital. di Scienz. Nat. a Milano,' vol. 21, p. 464; and 'Memorie della R. Accad. d. Scienz. d. Torino,' vol. 32, 1880, 28 Stu., 2 Tafeln.

¶ 'Arch. Ital. de Biol.,' vol. 10, fasc. III, p. 337

** 'Arch. f. Psych.,' vol. 6, p. 332, 1876.

†† *Ibid.*, vol. 7, p. 327, 1877.

Burckhardt,* in attempting to prove that the phenomenon is a reflex, measured the time which elapsed between the percussion of the tendon and the resulting muscular contraction. His investigations led him to the conclusion that it is a reflex which is produced in the spinal ganglia and not in the cord. Following him, numerous investigators endeavoured to determine the time which elapses between the stroke and the contraction.

Brissaud,† with Franck, measured the time very exactly in healthy persons, and also in those the subjects of disease. These observers found that 0·05 second elapses in healthy subjects, but that it varies from time to time in the same individual, and is modified by conditions which alter the excito-motor properties of the spinal cord. When the lateral columns of the cord are sclerosed the time is diminished; it is the same on the two sides in a healthy subject, but is less on that side when one lateral column is more sclerosed than its fellow.

Déjerine's‡ observations and Ter-Meulen's§ researches furnished very similar results.

Gowers,‖ who registered the movement of the limb in his observations, concluded that 0·09 to 0·015 second is the time which elapses between the stroke on the tendon and the resulting movement of the limb, which time is sufficient to allow a reflex to occur. Percussion of the tibialis anticus gave a response in 0·03 to 0·04 second, which is not sufficient for a cord reflex. He therefore concluded that ankle clonus is a phenomenon of direct excitation, while the knee jerk is to be looked on as a reflex.

Waller¶ found that the time which elapsed between percussion of the tendo Achillis and contraction of the gastrocnemius was 0·3 to 0·4 second, and in the case of the quadriceps extensor and its tendon 0·3 to 0·4 second. While admitting the necessity of the integrity of the spinal cord for its production, he did not admit its reflex nature, as the time was too short for a reflex to occur. He looked on the phenomena as merely peripheral reactions, and only tests of spinal conditions in the sense that other peripheral reactions of muscles (electrical or mechanical) are tests of these conditions.

Since then new facts with regard to the knee jerk have been recorded by several observers.

* "Ueber Sehnen-Reflexe," 'Festsch. V. Haller,' Bern, 1877.

† 'Recherches Anatomo-path. et Physiol. sur la Contracture perm. des Hémipl.,' Paris, 1880.

‡ 'Comptes Rendus,' May, 1878.

§ 'Ueber Reflexprikkenbaarhied en Pessreflexen,' Amsterdam, 1879.

‖ 'Lancet,' Part I, p. 156, 1879.

¶ 'Brain,' Part X, 1880.

Hughlings-Jackson* has recorded an instance of exaggeration of the knee jerk on one side after convulsions which affected chiefly the leg on that side. This observer has also published a case in which the knee jerks, absent in a case in which the posterior columns of the cord were sclerosed, returned when the lateral pyramidal tracts became sclerosed consequent on a cerebral hæmorrhage. Dr. Jackson has also observed that the knee jerks are absent in conditions attended by hyper-venosity of the blood in man.

Beevor† found that after generalised convulsions in man the knee jerks were absent or exaggerated according as the convulsions were very severe or less so, and the former condition he ascribed to exhaustion of the lumbar centres consequent on their severe discharge of energy.

Jendrassik‡ has furnished us with a valuable method of eliciting the knee jerk when it appears to be absent in healthy persons. It consists in making the person clench the hands or perform some other violent movement at the moment when the patella tendon is struck, when the resulting jerk is found to be increased. He concluded that the knee jerk is a true reflex caused by mechanical irritation of the nerves in the tendon; that passive tension of the muscle is necessary for its production; that voluntary innervation of the crural nerve lessens or prevents it; and that innervation of the sciatic favours it.

Weir Mitchell, and Lewis,§ from a large number of investigations in man, supplemented by a few in dogs and rabbits, concluded that the knee jerk varies in health, may be exhausted by too much use, and may increase from frequent excitation. All volitional acts may increase it; and weak innervation of the crural nerve increases it, as does any form of innervation of the sciatic, while strong prohibits it. Continual violent muscular actions, as of both arms and hands, eventually enfeeble the knee jerk. Passive tension is not essential for its production, moderate tension mechanically favours it, and extreme tension destroys it even in spastic cases. An act of will directed to a part functionally inert, or to amputated parts, reinforces the knee jerk. Strong or weak stimulation of one sciatic in etherised animals intensifies the knee jerk of the other leg; and pressure on the sciatic in man sufficient to cause pain and numbness diminishes the knee jerk on that side. One knee jerk does not reinforce the other. Touch has no effect on it, but all abrupt impressions such as pain, heat, and cold anywhere on the skin increase it, as does a

* 'Med. Times and Gaz.,' February, 1881; 'Brit. Med. Journ.,' July, 1891; February and March, 1892.

† 'Brain,' Part XVII, 1883.

‡ 'Deutsches Arch. f. klin. Med.,' vol. 33, p. 177, 1883.

§ 'The Medical News of Philadelphia,' February 13th and 20th, 1886.

violent optical impression. Nitrite of amyl has no effect on the jerk, but ether abolishes it in dogs, but has a smaller effect in rabbits. Faradic currents strong enough to produce contraction of muscles increase the knee jerk, and stimulation of the dry skin has a like effect. Short voltaic currents not strong enough to cause muscles to contract are attended by the same result, as are voltaic currents applied to the head, especially the temporal regions and especially when the negative pole is applied. Making is more effectual than breaking the current, and the effects soon wear away. Long ascending galvanic currents to the spine cause marked increase, while descending cause far less, and moderate currents do not reinforce the knee jerk. These results led these observers to conclude that the knee jerk is a direct muscular act, but that it cannot exist without that spinal contribution known as tone, which is capable of increase by a variety of causes. They consider that it cannot be a reflex, as the latter are inhibited by violent sensory stimulations, which they have shown increase the knee jerk. An exactly opposite view is that taken by Lombard,* who observed that the flexors, *i.e.*, the hamstrings, sometimes contracted when the ligamentum patellæ was struck. He concluded that the flexors were caused to contract by reflex excitation, and that the whole phenomenon was of the same nature.

Bowditch and Warren† found that when a voluntary action was employed to produce exaltation of the knee jerk the reinforcement wholly depended on the interval between starting of the action and the incidence of the blow to elicit the jerk. When this was prolonged, instead of being exalted, the knee jerk became much reduced; the interval at which the effect changes from positive to negative varied from 0·22 to 0·6 second. The effect of sudden auditory or visual stimulus was usually positive. Tactile stimulation of the conjunctiva and of the nasal mucous membrane also showed the same effect.

Bastian‡ has recently brought forward striking evidence to prove that in man total transverse lesion of the spinal cord above the lumbar enlargement abolishes, instead of augmenting, the knee jerks, as is commonly supposed; and Bowlby§ has supported this view by the results of his observations in fracture of the spine with crushing of the cord.

Buzzard|| has met with absence of the knee jerk in man when there was extravasation of blood into the cranial cavity.

* 'Journ. of Physiol.,' vol. 10, p. 122; 'American Journal of Psychology,' vol. 1, p. 50, 1887.

† 'Journ. of Physiol.,' vol. 11, p. 25, 1890.

‡ 'Med. Chir. Trans.,' vol. 73, 1890; 'Lancet,' March, 1890.

§ 'Med. Chir. Trans.,' vol. 73, 1890; 'Lancet,' May, 1890.

|| 'Med. Press and Circ.,' March, 1890.

History of Previous Experimental Work.

Experimental work directly bearing on the subject commenced with Schultz and Fürbringer,* who noted absence of the knee jerk after section of the crural nerve or lumbar roots in rabbits. A like result followed the administration of curara. They also showed that by striking the tendon on one side, under certain circumstances, not only that knee jerk could be elicited, but also that on the opposite side. The conclusions come to were that it is not the result of direct irritation of the muscle or its tendon, but a reflex act, the centre for which is situated in the lower part of the cord, and that there can be no question of its being in any sense a cutaneous reflex.

Tschiriew† excited the divided crural nerve electrically in order to give the muscle tonicity, but never succeeded in obtaining the knee jerk after it had disappeared on section of the nerve.

Burckhardt,‡ experimenting on rabbits, concluded that the duration of the phenomenon is less than the time necessary for a cutaneous reflex, that it subsists after section of the posterior roots of the spinal nerves and after destruction of the cord, but that it is abolished by section of the crural nerve; hence his belief that it is a reflex produced in the spinal ganglia and not in the cord.

Tschiriew,§ with the knowledge that the crural nerve in the rabbit is formed by the 5th and 6th lumbar roots, divided the cord at the level of the 3rd lumbar, and found that the knee jerk became exaggerated, while when the section was made between the 5th and 6th roots the knee jerk disappeared. On making successive sections from the sacral region upwards he found that the knee jerk remained intact until the level of the 6th lumbar pair was reached. He divided the posterior roots of the 6th lumbar pair, taking great care not to injure the neighbouring parts, and found that such section abolished the knee jerk. Destruction of the segment between the 5th and 6th lumbar pairs resulted in abolition of the knee jerk also.

Prevost,‖ in his first series of experiments, divided the cord in the dorso-lumbar region, whereupon the reflexes below this point became exaggerated. Section of the crural nerve abolished the knee jerk, as did section of the posterior root of the 6th lumbar in the rabbit, while it was augmented when the sciatic alone was divided. These experiments, therefore, confirmed the results of previous observers, especially those of Tschiriew. The next series of experiments were

* 'Centralbl. f. d. Med. Wiss.,' p. 929, 1875.
† 'Arch. f. Psych. und Nerv. Krank.,' vol. 8, p. 694.
‡ *Loc. cit.*
§ 'Arch. de Physiol.,' Series II, vol. 6, p. 293, 1879.
‖ 'Rev. Méd. de la Suisse Romande,' February, 1881.

entirely original on the part of Prevost, and deserve careful notice. He found that in the cat deep chloroform narcosis, and the administration of curara, each individually caused abolition of the knee jerk, while profound ether narcosis, almost up to the point of cessation of respiration, failed to do so. In the rabbit, on the other hand, profound ether narcosis abolished the knee jerk. Intravenous injection of 1 gramme of chloral in 10 grammes of water, injected in small quantities into a cat until the animal was profoundly insensible, failed to have any effect on the knee jerk. 3 grammes of water containing 0·075 gramme of the hydrochlorate of morphia, injected into a rabbit in the same way, caused exaggeration of the knee jerk, the animal being in a state of torpor with diminished respiration. The third series of experiments were also original, and consisted in compressing the abdominal aorta, and thus producing anæmia of the cord, and observing the effect of this on the knee jerk. Such compression, whether employed through the integument or applied directly to the abdominal aorta, in the rabbit caused in a few seconds exaggeration, and then abolition of the knee jerk in about 45 seconds, as a rule, and it remained absent for from 15 or 20 seconds to one or several minutes, after the compression was left off, before returning. The length of time that it remained absent was found to be directly proportional to the length of time that the compression on the aorta had been kept up; the longer the compression, the slower was the knee jerk in returning. The results obtained from the various methods of experimentation led Prevost to believe that the knee jerk has a decidedly central origin, and is of the nature of a reflex, also that it is the excitation of the tendon, and not of the skin, which elicits it. He further believed that the contraction of the opposite quadriceps when the tendon of one side is struck pointed to the existence of a crossed reflex.

Waller and Prevost* soon after performed some experiments in conjunction, which proved this last conjecture to be erroneous. They divided the sciatic, anterior, crural, and posterior roots on one side, and yet did not abolish the crossed movement. Percussion of the tendon on the injured side caused no contraction on that side, but evoked a contraction on the opposite side at least as vigorous as before the injury. From this they concluded that there was no physiological transmission, and therefore no "crossed reflex," but that the result was due to physical diffusion of vibrations.

Senator† found that the hemisection of the spinal cord affected the knee jerk on the same side only; that section or greater disturbance of the posterior columns of the lumbar cord, or of the posterior horns had no effect on the jerk; and that dividing the lateral

* 'Rev. Méd. de la Suisse Romande,' June, 1881.

† 'Arch. f. Anat. u. Physiol.,' Physiol. Abth., 1880, Heft 3.

column at the level of the 5th to the 6th lumbar vertebræ augmented the jerk on that side.

The latest experimental work on the subject is that by Sherrington,* who found that section of those branches of the anterior crural which supplied the vastus internus and adjoining part of the crureus abolished the knee jerk, while when these branches were left intact, and all the other branches of the nerve divided, the knee jerk remained active. He also noted that section of the 6th roots in rabbits did not always abolish the knee jerk, but occasionally section of the 5th root alone sufficed to bring about this result. In the cat, this observer found that when all the anterior and posterior nerve roots of the lumbo-sacral region, with the exception of the 6th, were divided, the knee jerk became brisk; but that section of the 6th root instantly abolished the jerk. When only half the filaments which composed the posterior root of the 6th root were alone divided the knee jerk was at once extinguished. Section of the anterior root of the 6th root greatly diminished, but did not absolutely abolish, the jerk; when, however, the ventral root of the fifth was subsequently divided in the same animal the knee jerk was abolished. In *Macacus rhesus* division of the 5th root never failed to abolish the knee jerk, while section of all other adjacent roots only tended to render it more brisk. Section of the whole, or even half, of the posterior root of the 5th abolished the knee jerk; but when the efferent root of the 5th was divided a remnant of the jerk persisted, as long as the efferent root of the 4th lumbar was left intact. Bisection of the cord in the lumbo-sacral region of *Macacus rhesus* produced no alteration in the knee jerk. Transverse section of the cord at the level of the 9th thoracic root caused the knee jerk to disappear ten minutes later, and it did not commence to return until three weeks after. A similar lesion of the cord at the level of the 1st lumbar root, with partial section at the 3rd lumbar, caused abolition of the jerk, and it did not return during the six months that the animal was under observation. When the knee jerk was abolished by the inhalation of chloroform it did not return so rapidly when the cord had been previously divided transversely as when it was left intact.

In a later paper† Sherrington has greatly added to our knowledge of the nerve arc on which depends the efficiency of the jerk. After showing how very readily the afferent fibres in the 5th lumbar posterior root (*Rhesus*), and on which the existence of the knee jerk depends, can be impaired, he proceeded to expand the observation of Tschiriew concerning the hamstring nerve, and he then found that excitation of this branch only of the sciatic trunk inhibited the jerk (thus excluding for the most part skin paths), and further that

* 'Journ. of Physiol.,' vol. 13, No. 6, 1892.

† 'Roy. Soc. Proc.,' February 9, 1893.

stretching (moderately and gently) a hamstring muscle would produce the same effect, thus proving that afferent impulses from the hamstrings normally inhibit the jerk.

The General Plan of Research.

In the present research various circumstances under which the knee jerk is altered are dealt with, and may, for convenience of description, be best arranged in two large groups.

A. Those circumstances under which the alteration in the state of the knee jerk is brought about by some influence locally exerted on the lumbar centres.

B. Those circumstances under which the alteration is due to some remote cause. In the first of these groups are included :—

I. The effects of asphyxia.
II. The effects of the inhalation of certain gases (nitrogen, nitrous oxide, and oxygen).
III. The action of anæsthetics (ether and chloroform).
IV. The effect of anæmia of the spinal centres as brought about by compression of the abdominal aorta, or by general loss of blood.
V. The action of intravenous injections of absinthe and strychnia respectively.
VI. The result of bisection of the spinal cord made vertically at the level of the centres in which the knee jerk appears to be represented.

The second group includes :—

I. The effect of removal of a cerebral hemisphere.
II. The immediate and late effects of extirpation of different parts of the cerebellum.

And as control experiments in this connexion.

1. The effects of extirpation of the labyrinth.
2. The effects of intracranial section of the 8th nerve.
3. The effects by chemical excitation of the 8th nerve.

In every instance those circumstances under which the knee jerk is exaggerated, and those under which it is abolished, are considered; but, inasmuch as both conditions may be brought about during different stages of the same influence, both of these states of the knee jerk are considered together.

Operative Procedure.

The anæsthetic employed to render the animal unconscious was invariably ether, except in those instances in which the effect of the action of chloroform on the lumbar centres was under consideration, when that anæsthetic was alone made use of throughout the experiment.

In every instance tracheotomy was performed, and narcosis kept up by allowing the animal to inhale the anæsthetic through the tracheotomy tube. When the effects of the inhalation of certain gases were under observation the tracheotomy tube was connected with a T-shaped glass tube by means of a short piece of india-rubber tubing; and india-rubber tubing was connected with the other two limbs of the T-tube, by which means it was easy to so arrange that the animal should inhale the particular gas from its reservoir, and exhale into the air of the room, the one tube being connected with the reservoir, and the other left free.

In those instances in which the heart beats were recorded the right carotid was exposed, opened, and a cannula inserted into it, which in turn was in connexion with a mercurial manometer. When a graphic record of the respiratory excursions was obtained it was made by means of a bertambour, whose elastic membranes were attached to a strip of Leslie's strapping which encircled the thorax. From this tambour an india-rubber tube led to a Marey recording tambour by which the respiratory excursions were registered on the cylinder.

In studying the effects of anæmia of the cord, the abdominal aorta was compressed, either by means of the thumb through the integuments, or directly after it had been exposed by dissection. General blood letting was effected by exposing and dividing one or both carotids.

Intravenous injections were made by injection with a hypodermic syringe into either a jugular or femoral vein, the minute opening made by the needle being closed by a small clip.

Bisection of the spinal cord was effected by exposing the cord at the level of the roots concerned with the knee jerk, inasmuch as division of it abolishes the phenomenon, and by means of a delicate thin-bladed knife, making a vertical incision along the middle line of the cord to the extent of two inches, with the root at its midpoint, and extending through to the anterior surface of the cord. In removing a cerebral hemisphere, a small disc of bone was first removed from one side of the cranium by means of a half-inch trephine, and then the opening was enlarged by bone forceps until the whole hemisphere was exposed. The dura mater was then dissected off, and the hemisphere removed *en masse*, or taken away piecemeal by means of a sharp scoop.

In the case of the cerebellum, a skin incision was made along the middle line down the back of the neck, and at its upper extremity a horizontal incision was carried across the vertex. The tissues were then scraped and cut away, until the occipital bone and arch of the atlas with the intervening occipito-atloid membrane were exposed; care being taken to work from the middle line outwards, as by this means hæmorrhage was found to be much less troublesome. When the superior vermis, or part of it, was to be removed, the bone covering this region was removed by means of bone forceps, and then the portion of the vermis desired excised by means of the knife. But when one or other lateral lobe was to be removed the occipital bone on that side was trephined by a half-inch trephine, and the opening increased by means of bone forceps. The dura was next dissected off, and then by means of a sharp scoop the lobe was scraped out. A syringe containing hot water (about 100° F.) was used to aid in the removal of the broken down cerebellar tissue, and in the arrest of hæmorrhage. The plan adopted in extirpating the labyrinth consisted in making a curved incision, commencing above, passing behind, and ending below the ear. The flap of skin with the pinna was then turned forward, all structures divided and scraped from the bone, so as to expose the meatus and the bone for a short distance around. The upper and posterior part of the meatus was then enlarged by means of a gouge, and by degrees the middle ear and then the labyrinth were cut into and cleared out.

When the 8th nerve was being exposed the skin incision varied little from that described above; but the bulla was more freely denuded of its soft coverings. The bulla was opened by means of a gouge, after which its inner wall was similarly cut through, until the 8th nerve was exposed. It was found that no appreciable length of the nerve could be exposed without lifting up the lateral lobe of the cerebellum, but that the nerve could be divided without interference with this structure. This plan of operation was sometimes followed in extirpating the labyrinth.

In both these methods of operating, hæmorrhage was profuse and troublesome, but was checked by the use of aseptic wax.

In those instances in which the animal was to be afterwards allowed to live the operation was conducted on strict antiseptic principles, the edges of the wound brought together by means of horse-hair sutures, and the wound dressed antiseptically.

In any instance where the operation was so severe as to lead one to suppose that the animal would be conscious of pain after the effect of the ether had passed off, a subcutaneous injection of $\frac{1}{2}$ or 1 grain of morphia was, as usual, given at the close of the operation, and repeated if necessary.

A. Circumstances under which the Alteration in the State of the Knee Jerk is brought about by some Local Action on the Lumbar Centres.

I. *The Effects of Asphyxia.*

Asphyxia was produced either by clamping a short piece of india-rubber tubing fixed to the free extremity of the tracheotomy tube, or by inserting an india-rubber plug into the tracheotomy tube directly. Before inducing asphyxia the knee jerks were carefully and repeatedly tested in order to be certain that the depth of narcosis was not such as to cause any material alteration in the state of their condition. When it was satisfactorily determined that they were as nearly as possible normal, cardiac and respiratory tracings were taken for some seconds before the tracheotomy tube was plugged. The immediate effects on the respiratory and cardiac movements do not call for description; that they were those usually met with under similar conditions is shown in fig. 1.

1. *The Effects of Asphyxia on the Lumbar Centres with the Spinal Cord Intact.*—The first effect which the altered conditions of the blood had on the knee jerk was to cause it to become exaggerated; this quickly became more and more marked, until clonus at the knee was produced by a single tap on the patella tendon; and when the exaggeration was at its maximum a tap on one tendon not only produced clonus on that side, but also evoked the knee jerk on the opposite side, even to the extent of a few clonic jerks. After this stage was reached the knee jerk became less and less marked, until it disappeared completely, and did not return up to the time of the death of the animal, when this was allowed to take place. But if, instead of allowing the animal to die, the obstruction to the entrance of air into the lungs was removed, and the animal recovered either with or without the aid of artificial respiration, the knee jerk reappeared. The time which elapsed before its reappearance depended on the length of time that the asphyxial state had been kept up; the shorter the duration of this state the quicker did the knee jerk return, and *vice versâ*. On its return the knee jerk did not at once present its normal characters; at first feeble, it quickly passed into a state of exaggeration, sometimes to the extent that a single tap on the patella tendon evoked a few clonic jerks; after a variable period this exaltation subsided, and it returned to its normal condition. The stages in the asphyxial state to which these different phenomena are related are indicated in fig. 1, which shows the respiratory and heart tracings obtained from a dog. About 2 minutes after the trachea was clamped the stage of asphyxial convulsions was reached, and after the blood pressure had risen the knee jerk

became exaggerated. This exaggeration amounted to clonus in about 30 seconds later; but about $1\frac{1}{2}$ minutes later, and after the stage of asphyxial convulsions, the knee jerk was abolished, while the blood pressure was still high, though showing signs of commencing to fall. Artificial respiration was commenced about a minute after this (see fig. 2), and $1\frac{1}{2}$ minutes afterwards the knee jerks returned, became exaggerated in about 50 seconds, and returned to their normal state about $2\frac{1}{2}$ minutes later.

The exact times at which the various phenomena occurred varied in different animals of the same class, and more widely in animals of different classes. Fig. 3 shows the approximate times at which they occurred in one of the rabbits used. In this particular instance the knee jerk became exaggerated about 50 seconds after the tracheotomy tube was plugged, and it was abolished about 70 seconds later. The plug was removed from the tracheotomy tube about 10 seconds after this, and in about 10 seconds the knee jerk returned; in about 12 seconds it became exaggerated, and returned to its normal condition after 60 seconds. In fig. 4, besides the blood and respiratory curves, a tracing of the asphyxial convulsions is shown, as obtained from the extensor muscles of the forearm of the dog, in order to show that the knee jerks were still exaggerated for some time after the convulsions had ceased.

It will thus be seen that exaltation of the knee jerk is a phenomenon of the so-called first and second stages of asphyxia, while its abolition is related to the third stage of that condition. Figs. 5 and 6 are intended to show what relationship exists between the alteration in excitability of the spinal centres and that of the cortical cells. Although the cortex exhibits some diminution in its excitability before the knee jerk is lost, yet its excitability is not completely annulled until some time after all attempts to elicit a knee jerk have failed. The preliminary exaggeration of the knee jerk commences to show itself before there is any sign of diminution of the cortical excitability.

2. *The Effects of Asphyxia on the Lumbar Centres after Total Transverse Section of the Spinal Cord in the Mid-dorsal Region.*—By this means any influence of the cerebrum and cerebellum on the phenomena was entirely excluded. It was found that, with the exception of commencing the experiment with a knee jerk more active than when the cord was not previously divided, the phenomena evoked by the asphyxial state were in every way identical to those observed before the cerebrum and cerebellum were excluded from taking any possible part in, or exerting any influence upon, their production.

II. *The Effects of the Inhalation of Certain Gases.*

1. *Nitrogen.*—As has been already noted, a T-tube was made use of in these experiments; one limb of the T being connected with the tracheotomy tube, one by means of india-rubber tubing, with the gas reservoir, and one being left free with a small piece of india-rubber tubing fitted on to its extremity. The tube leading from the gas reservoir was grasped between the fingers and thumb of one hand, while the piece of tube at the extremity of the free limb of the T was grasped between the fingers and thumb of the other hand. During inspiration the free end was closed, while the tube from the bag of nitrogen was left free, and during expiration the tube from the nitrogen was closed, and that opening into the air of the room was opened. In this way nitrogen gas was alone inspired, while expiration took place into the air of the room.

Except that it took a longer time to obtain the results, the effects were identical with those met with in asphyxia.* The loss of knee jerk was preceded by the stage of exaltation, and when the animal was allowed to recover the absence of knee jerk was followed by a stage of slighter exaltation before its return to the normal state, such as existed before the administration of the nitrogen.

2. *Nitrous Oxide.*—The plan of procedure was the same in these experiments as in the last, and the results differed from them in no way. Loss of the knee jerk was always preceded by a stage of exaltation, and when the animal was allowed to recover, the normal state of the knee jerk was only reached after passing through a period during which it was exalted.

3. *Oxygen.*—Here again the plan of procedure was the same as in the experiments with nitrogen; but the results were widely different. Indeed, they were totally different from any that had been previously obtained, for in no case was the knee jerk abolished, no matter how long the so-called apnœic state was kept up. Increased activity of the knee jerk, gradually becoming more so until clonus developed, was the only effect of inhalation of this gas. When its administration was discontinued the knee jerk gradually returned to the condition in which it was before the inhalation of oxygen was commenced.

III. *The Action of Anæsthetic Agents.*

1. *Ether.*—In profound narcosis induced by the inhalation of ether the knee jerk is abolished; but this stage is preceded by one of increased activity, and followed by a similar stage of exaltation when the animal is recovering from the effects of the anæsthetic, and before the knee jerk returns to its normal conditions. The length of time

* *Cf.* Martin, 'Journ. of Physiol.'

that the knee jerk remains absent depends entirely on the depth of narcosis, and the length of time this is continued, these bearing a direct ratio to each other. The exaggeration of the knee jerk which has been alluded to is never so pronounced as in simple asphyxia or the condition induced by nitrogen or carbonic oxide; but it is nevertheless perfectly distinct.

2. *Chloroform.*—The results obtained were identical with those obtained with ether, with two important exceptions, however; thus, the knee jerk is lost very much more rapidly under its influence than under the influence of ether, and after the administration of the narcotic is discontinued a longer period elapses before the knee jerk shows any sign of returning than after a similar depth and duration of ether narcosis.

These effects with ether and chloroform were obtained both when the spinal cord was intact and when it had been previously divided transversely in the mid-dorsal region.

IV. *The effect of Anæmia of the Spinal Centres as brought about by Compression of the Abdominal Aorta or by General Blood-letting.*

1. *Compression of the Abdominal Aorta.*—This was effected by means of the thumb, either through the structures composing the abdominal wall in the rabbit, or after the artery had been exposed by dissection (rabbit and dog). The resistance offered by the bony spinal column makes it exceedingly easy to entirely stop the flow of blood in the aorta beyond the point at which compression is made by the thumb. As Prevost* found, after the compression had been kept up a short time the knee jerk disappeared, and the time that it continued absent after the compression had been taken off varied directly as the time that the compression had been maintained; the longer the compression, the longer did the knee jerk afterwards take to return. Before the knee jerk was abolished, and after it was abolished and before it returned to its normal state, it passed through stages of exaltation, as has been already observed to be the case in other conditions attended with loss of the knee jerk.

2. *General Blood-letting.*—The carotid artery was opened on one or other side, and the animal allowed to gradually bleed to death. As more and more blood was lost so the knee jerk became more and more active at first; but after a time it gradually became less so, until it eventually disappeared entirely, and did not reappear up to the time of the death of the animals.

* *loc. cit.*

V. *The Action of Intravenous Injections of Absinthe and Strychnia.*

1. *Absinthe.*—The action of this drug on the lumbar centres was tried, both when the spinal cord was intact and after transverse section of it in the mid-dorsal region. As has been explained, a jugular or femoral vein was exposed, and varying doses of the essential oil of absinthe were injected into it, according to the class of animal under observation and the particular effect which was aimed at. Doses short of those necessary to evoke generalised convulsion were attended by increase of the knee jerk, whether the cord was intact or divided in the dorsal region. Doses sufficiently large to evoke powerful generalised convulsions were also followed by increase of the knee jerk after the convulsions ceased.*

When the spinal cord had been previously divided transversely in the dorsal region, and the lower extremities thus excluded from the otherwise general convulsions, the increase of the knee jerk, after large doses of absinthe, was still observed. The increase never amounted to clonus or tonus, but was nevertheless well marked. This effect of absinthe on the lumbar centres was strikingly demonstrated in the following experiment. The spinal cord of a dog was divided transversely in the mid-dorsal region when the animal was so profoundly under the influence of ether that the knee jerk could not be obtained. The animal was then kept lightly under the influence of the anæsthetic, but, in spite of this, the knee jerk had not returned fifteen minutes after the cord had been divided. Three minims of the essential oil of absinthe were then injected into the femoral vein of one side, and the knee jerk of the opposite side kept under observation. Well-marked convulsions occurred in a few seconds, limited to those parts above the spinal cord lesion, while the parts below the lesion remained inactive. At the time that the convulsions above the cord lesion were at their height there was doubtful evidence of return of the knee jerk. As there was absolutely no sign of the presence of the knee jerk ten minutes after the first injection of absinthe was given, 2 minims more of the essential oil were injected into the same vein. As before, convulsions occurred in those regions whose nerve supply was derived from the central nervous system above the lesion in the spinal cord, while those regions which derived their supply from below this point remained passive. A few seconds after this further administration of the drug there was undoubted return of the knee jerk, which persisted for a minute or two and then disappeared. Ten minutes after the second dose of absinthe was given a third dose of 2 minims was injected into the same vein as on the two former occasions with exactly similar results with respect to the convulsions. The knee jerk was obtained a few seconds after the

* Beevor, *loc. cit.*

absinthe had been injected, and did not again disappear in the course of half an hour, during which time it was under careful observation.

2. *Strychnia.*—The effect of this drug was only tested in the dog. Two minims of a 1 per cent. solution of strychnia were injected into the femoral vein, after the spinal cord had been previously divided transversely in the mid-dorsal region. Powerful convulsions quickly followed in all parts whose nerve supply was derived from above the cord lesion, while those whose nerve supply was from below this point remained free from convulsion. The knee jerk was increased at first slightly, but soon more so, and on injecting 1 minim more of the same solution of strychnia into the femoral vein as before, a single tap on the patella tendon was sufficient to evoke tonus in the quadriceps extensor.

When strychnia was administered without the spinal cord being previously divided, general convulsions of course resulted, and these seriously interfered with the observations on the knee jerk, as even when the animal was not in a comparatively quiescent state a tap on the quadriceps tendon usually sufficed to evoke convulsions. The plan of first dividing the spinal cord transversly in the dorsal region was therefore that usually adopted in observing the effects of strychnia on the knee jerk, and in all cases there could be no question as to the increase of the jerk under the influence of this drug.

VI. *The Results of Section of the Spinal Cord.*

1. Transverse Section.
2. Vertical Section.

1. *Transverse Section of the Spinal Cord.*—It has long been recognised that in the lower animals complete transverse section of the spinal cord above the level of the lumbar enlargement is followed by increased activity of the knee jerk. My own experiments in the dog show that the immediate effect of such a lesion depends on the depth of narcosis. The cord was always divided at or about the mid-dorsal region, and in no instance did the knee jerk disappear after such section of the cord when there had been no doubt as to its presence before the lesion was inflicted, while usually there was no difficulty in being certain of its increased activity under such circumstances. The depth of ether narcosis, however, plays a most important part in this connexion, for if the cord were divided when narcosis was so profound that the knee jerk was almost abolished, the section of the cord hastened the result; and when the cord was divided when the depth of narcosis was such that the knee jerk was abolished, the latter remained absent for a much longer time than is usual after

suspension of the administration of the anæsthetic when the spinal cord has not been divided.

2. *The Effect of Bisection of the Spinal Cord vertically at the level of the centres on whose activity the knee jerk depends.*—These experiments were undertaken to ascertain whether or no the centres to which the knee jerks are related are separate and independent in their action on the two sides, or whether the centre on one side is in any way related to its fellow of the opposite side, and depending on its co-operation for the proper performance of its functions. Since these experiments were performed Dr. Sherrington has published the results of similar experiments carried out by himself in connexion with the lumbar cord of *Macacus rhesus*. My results entirely agree with his, and showed that dividing the cord into two lateral halves, the incision commencing at the level of the 1st lumbar roots and extending to the level of the 1st sacral pair, had no appreciable effect, either in increasing or diminishing the knee jerks.

B. Circumstances under which the Alteration in the State of the Knee Jerk is due to some Remote Cause.

I. *The Effect of the Removal of a Cerebral Hemisphere.*

Either hemisphere was selected, and during the process of exposing it great care was taken to prevent the animal from losing more blood than was absolutely unavoidable. When everything was ready for the removal of the hemisphere the knee jerks were carefully tested, so as to be certain that nothing had occurred to render them unequal during the preparatory operation. The hemisphere was then excised after the dura mater was dissected off it. The effect was immediate and striking, the knee jerk on the opposite side of the body becoming distinctly more active than that on the same side as that on which the cerebral hemisphere was removed, this inequality being due to an increased activity of the knee jerk on the opposite side, and not to a diminished activity of that on the same side.

II. *The Immediate and Late Effects of Extirpation of Portions of the Cerebellum.*

1. *The Immediate Effect of Extirpation of Portions of the Cerebellum.*—*a.* The removal of one lateral lobe was followed by great exaggeration of the knee jerk on the same side, while that on the opposite side was considerably diminished. So great was the exaltation of the knee jerk on the same side as that on which the cerebellar lobe was excised, that often a single tap on the patellar tendon sufficed to produce tonic extension of the limb.

When after extirpation of one lateral lobe of the cerebellum the opposite one was also removed, the knee jerk on the side corresponding to that on which the lobe was more recently removed became increased, while there was some diminution of the knee jerk on the side on which the lobe was first removed, the two knee jerks being as nearly as possible equal, and, while both knee jerks were exaggerated, they were not as much so as was the one when only one cerebellar lobe was removed.

The depression of the knee jerk on the opposite side under these circumstances was a phenomenon less marked than was the exaltation of that on the same side as that from which the cerebellar lobe had been removed. In order to test this point further, one cerebral hemisphere was first removed, with the result that the knee jerk on the opposite side became more active than it was before.

A curious and interesting ether effect was observed in connexion with this difference of the knee jerks on the two sides when one lateral lobe of the cerebellum was removed. While the above results obtained during ordinary moderate ether narcosis, the result was exactly the reverse when anæsthesia was very profound, for then the knee jerk which was formerly exalted became depressed, even abolished, while that which was formerly lessened became markedly exaggerated.

The lateral lobe of the cerebellum on the same side as that on which the cerebral hemisphere was removed was next extirpated, when the active knee jerk on the opposite side became less so.

On account of the risk of complication by injury of other parts, no attempt was made to do more than remove the whole of the *posterior* part of the vermis of one lateral half of this posterior portion. When only the half of this posterior portion was removed, there was slight increase of the knee jerk on the same side, but this increase was in no way comparable to the great exaggeration which followed removal of one lateral lobe. As far as could be determined, the knee jerk on the opposite side was in no way altered by this lesion. When the whole of the posterior portion of the vermis was removed both knee jerks became slightly increased.

2. *The Late Effects of Extirpation of Portions of the Cerebellum.*—On the day after the operation of removal of one lateral lobe of the cerebellum the knee jerk on the same side was still exaggerated, though less so; but although the knee jerks on the two sides were still unequal, that on the opposite side was no longer feeble, but was slightly exaggerated. In the course of the second and third days it became difficult to be certain that any inequality existed on the two sides, both knee jerks being very much exaggerated, though neither of them as much so as was the one on the side of the lesion immediately after the operation. A month or six weeks after the

operation most of the animals showed a slight inequality of the knee jerks, so that, although both were exaggerated, that on the side corresponding to that from which the cerebellar lobe had been removed was slightly the more so; but in some animals the inequality was not evident. When half of the posterior part of the vermis was removed, it was usually difficult next day to say which knee jerk was the more active; but, as in the case of the lateral lobe, after a few weeks a difference on the two sides could be once more detected in most of the animals. At this time the knee jerk on the opposite side was usually as nearly as possible normal, while that on the same side as the cerebellar lesion was more active than normal. In like manner the increase of knee jerk produced by removal of the whole of the posterior portion of the vermis persisted.

If, after a one-sided lesion, either of the vermis or lateral lobes, the animal was placed under the influence of ether, the inequality of the knee jerks became more pronounced; and if the anæsthetic was pushed to the point at which abolition of the knee jerks results, that on the opposite side usually disappeared sooner than did that on the side corresponding.

There seemed, therefore, little reason to doubt that the effects obtained in connexion with the knee jerk when portions of the cerebellum were removed were directly the result of the cerebellar lesion. However, Professor Victor Horsley kindly drew my attention to the fact that the proximity of the auditory nerve and labyrinth made it necessary to institute control experiments, with a view to excluding the possibility of the effects being wholly or partly due to interference with one or other, or both, of these structures. He suggested that the labyrinth should be extirpated on one side in some animals, while in some others the 8th cranial nerve on one side could be subjected to chemical excitation. I accordingly performed the following control experiments.

III. *Extirpation of the Labyrinth on one side.* (*Control.*)

No inequality was produced in the knee jerks by this at the time of the operation, nor was any alteration detected two weeks after the operation, except in one instance, in which, two weeks after the operation, the knee jerk on the same side as the ear lesion seemed slightly more active than its fellow of the opposite side. As there was suppuration in the deep wound in this case, it was thought that the result probably depended on entrance of pus into the region of the lateral lobe of the cerebellum on the same side, but no such condition was macroscopically obvious at the autopsy, so that this case is difficult of explanation.

IV. *Intracranial Division of the 8th Nerve on one Side. (Control.)*

No inequality in the knee jerks was produced, either at the time of the operation, during the few hours immediately following the operation, or at any time during the week, after the section of the 8th nerve.

V. *Chemical Irritation of the 8th Nerve on one Side. (Control.)*

It was found impossible to expose a sufficient length of the nerve to apply an irritant to it without lifting up the lateral lobe of the cerebellum. As any interference with the cerebellum would have vitiated the experiment, it was decided that, instead of applying the irritant directly on the nerve, it should be placed in the labyrinth instead. Accordingly the labyrinth was opened, and a small portion of the 8th nerve exposed as it entered the labyrinth. Crystals of chloride of sodium were next carefully packed around the stump of the nerve and kept in position by means of a plug of aseptic wool introduced into the labyrinth. The knee jerks were carefully tested immediately after the operation, and frequently during the same day, but no alteration could be detected in them, and they remained normal and equal on the two sides during the week that they were kept under observation.

Summary and Conclusions.

I. *The Effects of Asphyxia.*

The results obtained in asphyxia appear to be due in great measure to cutting off the supply of oxygen to the lumbar centres. The preliminary exaggeration of the knee jerk might have been due to the taking off of cortical control from the lumbar centres, letting them go, so to speak, as suggested by Hughlings-Jackson,* for, as numerous experimenters have shown, asphyxia diminishes, and in an extreme degree annuls, the excitability of the motor cortex. That this hypothesis cannot be entertained is proved by the following facts. At the time when the knee jerk first becomes exaggerated the excitability of the motor cortex is little, if at all, diminished, and is not annulled until a considerable time after the knee jerk is abolished. Further, and this appears to me more conclusive evidence, the same exaggeration of the knee jerk was met with when asphyxia was induced in animals whose spinal cords were divided above the lumbar enlargement, in which case any cerebral influence was entirely put out of court. As far as the preliminary exaltation of the knee jerk is con-

* 'Brit. Med. Journ.,' February, 1892.

cerned, therefore, we must look to the spinal centres alone for explanation of the phenomenon. The rise of blood pressure which occurs in the first stage of asphyxia might be held accountable for the exaltation of the knee jerk; but that this is not the true explanation seems evident, owing to exaltation being met with in anæmia of the cord, and in the marked fall of blood pressure in general blood letting. That it is due to an irritable condition of the lumbar cells induced by depriving them of their normal supply of oxygen is rendered probable from the following facts, as well as those just mentioned.

What part, if any, the presence of excess of carbonic acid in the lumbar centres plays in the production of the phenomenon, it is difficult to estimate. That the absence of oxygen is alone capable of producing it is shown by the effects of anæmia of the cord, and by the fact that when nitrogen gas is inhaled the same result is obtained; for in this latter instance most of the oxygen in the body is used up, and the nitrogen takes its place, but there is not necessarily any excess of carbonic acid, since there is no obstruction of expired air, merely the entrance of nitrogen instead of oxygen being provided for. One thing is, however, evident, viz., that in all these conditions the effect is not so rapid as in asphyxia; therefore it is not improbable that the presence of excess of carbonic acid hastens the results.

The abolition of the knee jerk might be due to exhaustion of the lumbar centres by the asphyxial convulsions, for Beevor* has shown that after severe epileptic convulsions in man the knee jerk may be abolished, and this has been attributed to exhaustion of the lumbar centres, consequent on their great discharge of energy. That this is not the explanation of the phenomenon in asphyxia is proved by the fact that it occurs when the spinal cord has been divided transversely in the dorsal region prior to the occurrence of asphyxial convulsions, and where, therefore, the lumbar cells are not discharged during the asphyxial spasms, and consequently cannot be exhausted in this way. Indeed it appears not improbable that the effects in man which have been attributed to exhaustion of the lumbar centres may after all be due to the asphyxiated condition of the blood, which occurs in a severe epileptic seizure, consequent on the arrest of respiration due to the tonic spasm of the muscles of respiration.

That the failure of the knee jerk is consequent on the fall of blood pressure which takes place in the third stage of asphyxia seems improbable, as the knee jerk is lost just when the blood pressure commences to fall, often, indeed, before there is any distinct evidence of the decline of blood pressure. Then also in general loss of blood the blood pressure falls very considerably lower than the height at which it stands when the knee jerk is lost in asphyxia without any sign of loss of knee jerk, which does not take place till much later.

* *Loc. cit.*

I trust, therefore, we are justified in concluding that the failure of the spinal centres, to which the knee jerk is related, to perform their functions is due in large measure to their being starved of oxygen; for this same starvation occurs in asphyxia when nitrogen or nitrous oxide is inhaled, and when anæmia of the lumbar cord is produced; in all these conditions abolition of the knee jerk being the ultimate result observed.

With regard to the part played by carbonic acid in helping to bring about this effect, what has already been said with reference to the preliminary exaltation of the knee jerk is wholly applicable; therefore nothing further need be said on this subject.

The behaviour of the knee jerk when it reappears after being absent for a time, taken in connexion with its behaviour when first deprived of its normal supply of oxygen, and before it was abolished, suggests the probability that not merely the presence of oxygen is necessary for the lumbar cells to functionate normally, but a certain definite quantity of that gas. And this normal balance appears to be upset either by an insufficient quantity of the gas, or by too much of it; for when pure oxygen is inhaled the same exaltation is observed.

II. *The Effects of the Inhalation of certain Gases.*

The results obtained with nitrogen and nitrous oxide, coinciding as they do with those obtained in asphyxia, lend strength to the hypothesis which has been advanced in explanation of the phenomena related to asphyxia; for when either of these gases is inhaled, to the entire exclusion of all atmospheric air, the blood is principally deprived of its oxygen, and so also the lumbar centres. Here, again, it is therefore probable that the absence of oxygen is to be looked on as the prime factor which brings about the alterations in the knee jerk, which have been already detailed, the exact form of alteration apparently depending on the amount of oxygen left in the blood. When the amount of oxygen in the blood is small, or only moderate, the lumbar centres become more excitable, while when it is absent, or only present in very minute traces, inaction of these centres results.

III. *The Effects of Ether and Chloroform.*

That the results obtained with these drugs are due to their direct action on the lumbar centres is shown by the fact that the results are almost identical, whether these centres have or have not been cut off from their connexion with higher centres by complete transverse section of the cord in the dorsal region. It is a little curious that the lumbar centres should show the same increased excitability when

these poisons have acted on them for a certain time, just as when they have been deprived of a certain amount of their supply of oxygen. That they should fail to act after they have been subjected to the influence of such powerful poisons is not surprising. It may, of course, be urged that the results obtained with these drugs are not the result of their specific action on the lumbar centres, but of the want of oxygen. While it cannot be denied that this may play some part in the production of the phenomena, that the direct action of the poisons is mainly responsible there can be little doubt, for during the respiration of these vapours, in the manner employed in their administration to animals, the entrance of atmospheric air is not excluded, so that, while possibly the interference with the supply of oxygen to the lumbar centres might account for the preliminary exaltation of the knee jerk, it can never be nearly so great as to bring about the abolition of the knee jerk, which, as has been shown, takes a considerable time to disappear, even after the fresh supply of oxygen to the blood has been completely cut off. Further, and this is more convincing, the effects of chloroform and ether respectively differ in two important respects, since (1) the effects on the knee jerk are brought about very much more rapidly when chloroform is inhaled than when ether is administered, and (2) the effect produced by chloroform continues longer after its administration is discontinued than does the same effect when produced by ether. Nothing but certain inherent properties of these drugs can be reasonably believed to be the causes of these differences, for, if venosity of blood was alone or mainly responsible for the results, the effects produced by ether should be more rapid and powerful than those produced by chloroform, since greater venosity is observable in the case of the former than the latter drug. It seems not unreasonable to assert, therefore, that the results obtained with ether and chloroform are mainly due to the direct action of these drugs on the lumbar centres.

IV. *The Effect of Anæmia of the Spinal Centres.*

Deprivation of the lumbar cord of its blood supply, either by direct pressure on the abdominal aorta or by general blood letting, is synonymous with depriving it of its normal supply of oxygen. But another factor has to be taken into consideration in this relation, for both of these methods of experimentation are attended with notable lowering of the blood pressure in the lumbar cord. That the shock occasioned by such lowering of blood pressure, whether resulting from the more or less sudden effect of clamping the aorta, or the more gradual lowering in general loss of blood, is capable of causing abolition of the knee jerk is not improbable; but that this is the true explanation of the occurrence of the phenomena is made improbable,

when it is remembered that exaltation of the knee jerk precedes its disappearance, for in no known method of producing shock of the spinal cord is there an increased excitability of its centres before their failure to act. It seems, therefore, more feasible to attribute the whole of the result, as far as exaltation of the knee jerk is concerned, to the absence of oxygen.

V. *The Action of Intravenous Injections of Absinthe and Strychnia.*

On the supposition that the former of these drugs acts mainly on the cerebral cortex, and possibly in some degree on the bulbar centres, but little, if at all, on the lower spinal centres, this drug was given in doses sufficiently large to produce powerful generalised convulsions, in order to test whether or no there is any evidence of exhaustion of the lumbar centres after such discharges, when the paths from these centres to the cerebrum, and from the cerebrum to them, are left intact. It was found that, in spite of the most powerful and oft-repeated generalised convulsions, there was increased action rather than depression of the lumbar centres, as evinced by increase of the knee jerk. That this was not a fair test of the condition of the lumbar centres, as comparable to their condition when generalised convulsions result from some condition which evokes discharge from the higher centres alone, is proved by the results obtained with absinthe, when the lumbar cord had been severed from its connexion with the higher centres by complete transverse section of the cord in the dorsal region. When this was done it was found that, though no convulsions in those parts enervated from the spinal cord below the level of the transverse lesion, yet there was abundant evidence of a considerable direct action on the spinal centres, as proved by the re-establishment of the knee jerk when its absence probably depended on shock to the lumbar centres, and of its increased action when it was comparatively normal before the administration of the drug. That strychnia should cause increase of the knee jerk, whether the spinal cord was intact or divided transversely in the dorsal region, was only what was expected from the well-known powerful action of the drug on the spinal cord. It is thus clear that absinthe, like strychnia, has a direct action on the lumbar centres, but that this action is very much less pronounced in the case of the former than in that of the latter drug.

VI. *The Results of Section of the Spinal Cord.*

That complete transverse section of the spinal cord, sufficiently high up not to interfere with the lumbar centres either by direct mutilation, shock, or myelitic softening consequent on the lesion, does not

abolish the lesion in the lower animals, but, on the contrary, causes distinct increased activity of it, is a well-established fact, which did not require the further support which the results of these experiments give to it. The chief interest in the present experiments, however, is centred in the varying effect obtained according to the depth of ether narcosis; and they demonstrate very clearly how greatly shock to the spinal cord may be increased by the depth of narcosis. That is, a lesion of such severity and in such a situation as to cause very little or no shock to the lumbar cord under moderate ether narcosis may be made to produce considerable shock if the depth of narcosis be greater at the outset.

The results of bisection of the spinal cord in the lumbo-sacral region prove, in confirmation of Sherrington's observations, conclusively that the centres on whose action the knee jerk depends are distinct in the two lateral halves of the cord, and are not dependent on each other, either for control or for reinforcement.

The Effects of Removal of a Cerebral Hemisphere.—The increase of the knee jerk on the opposite side, which followed the removal of the cerebral hemisphere of one side, is a result in keeping with the best established views of the relation of the lower spinal centres to the higher cortical ones; for by removing the hemisphere the control which the cortical centres are regarded generally as exercising over the spinal centres of the opposite side chiefly was removed.

The Immediate and Late Effects of Extirpation of portions of the Cerebellum.—As has been seen, the knee jerk on the same side became exaggerated both when one lateral lobe of the cerebellum or when one half of the posterior part of the vermis was removed, and that this increase of the knee jerk persisted for weeks, *i.e.*, after all phenomena which could be ascribed to "irritation" had passed off. It seems justifiable therefore to attribute this to a "paralytic" rather than an "irritative" lesion. This being the case, two hypotheses are open to us in explanation of the phenomenon: either we must suppose that the one half of the cerebellum exercises an energising influence on the opposite half of the cerebrum, in virtue of which it causes the opposite cerebral centres to hold in greater check the spinal centres of the side of the spinal cord corresponding to the side of the cerebellar lesion; or that the one half of the cerebellum exercises a controlling influence on the spinal centres on the same side of the spinal cord. If the first of these hypotheses is accepted, then the increase of the knee jerk is due to the diminished power of control of the cerebral centres on those in the spinal cord in consequence of the loss of the energising influence of the cerebellum on the cerebrum. If, on the other hand, the second of these hypotheses be accepted, the increase of the knee jerk is due directly to the taking off of cerebellar control from the spinal centres. That the first of these hypotheses

does not wholly meet the case is, I think, clear on two grounds. The increase of the opposite knee jerk which is consequent on the removal of the cerebral hemisphere of one side is not nearly so great as that brought about by the removal of the lateral lobe of the cerebellum of the same side. When one cerebral hemisphere has been first removed, and the opposite lateral lobe of the cerebellum is removed, the knee jerk on the opposite side from the cerebral and on the same side as the cerebellar lesion is further increased after the second operation. It thus seems clear that the cerebellum exercises an independent action on the spinal centres from that exercised by the cerebrum, and that this action is of the nature of a control over the spinal centres chiefly of the same side. That this is the chief explanation of the phenomenon there appears little doubt; but it does not entirely negative the possibility of the first hypothesis being wholly or in part true.

The fact that the diminution of the knee jerk, on the side opposite to that on which the lateral lobe of the cerebellum was removed, was always of such short duration, points to that phenomenon as being an "irritative" one, possibly one of inhibition.

The curious ether effect which was observed in this connexion is easy of explanation as far as the knee jerk of the opposite side is concerned, when it is considered alone; for, if it be admitted that the inhibitory influence of the cerebellar lesion is sufficient explanation for the occurrence of diminution of the knee jerk, it is easy to understand how the first effect of the ether would be to remove this inhibitory influence, and by its direct action on the spinal centres to cause exaggeration of the knee jerk. The effect of the ether on the knee jerk of the same side as the cerebellar lesion is also easy of explanation, when considered by itself, for the direct effect of the ether on the spinal centres, when present in sufficient quantity, would be to cause diminution, and finally abolition, of the knee jerk. When both phenomena, *i.e.*, those of the opposite sides, are considered together, the explanation becomes more difficult; for, in order that the explanations suggested when the phenomena were separately considered should hold good now that they are considered in conjunction, one of two things must be admitted: either some influence on the spinal centres of the side corresponding to that of the cerebellar lesion has rendered them less capable of resisting the direct action of the ether; or some influence acting on the spinal centres of the opposite side has rendered them more resistant to the action of that drug.

These questions must for the present remain unanswered.

That interference with the 8th nerve or labyrinth plays no part in the phenomena which follow extirpation of parts of the cerebellum is abundantly proved by the control experiments which were performed in order to decide this question.

DESCRIPTION OF FIGURES.

FIG. 1 is intended to show the stages in the asphyxial state at which the knee jerks become exaggerated and are abolished.

a = Curve from carotid artery.
b = Respiratory curve.
c = Time curve.

FIG. 2 shows the stage when the knee jerk returns, after it has been abolished, and that it becomes exaggerated before returning to its normal condition.

a = Curve from carotid artery.
b = Respiratory curve.
c = Time curve.

FIG. 3 indicates the stages in the asphyxial state at which the alterations in the condition of the knee jerk occur in the rabbit.

a = Curve from carotid artery.
b = Respiratory curve.

FIG. 4 shows the stages in the asphyxial state at which the knee jerk becomes exaggerated and is abolished, and how these phenomena are related, in point of time, to the asphyxial convulsions.

a = Curve from carotid artery.
b = Respiratory curve.
c = Time curve.
d = Curve obtained from the extensor muscles of the wrist during the asphyxial convulsions.

FIG. 5 shows that a response can be obtained on excitation of the motor cortex after the knee jerk has been abolished.

a = Curve obtained from carotid artery.
b = Respiratory curve.
c = Curve obtained from extensor muscles of the wrist on a single excitation of the cortex cerebri.

FIG. 6 shows that the motor cortex remains excitable after the stage at which the knee jerk is abolished.

a = Curve from carotid artery.
b = Curve obtained from the extensor muscles of the wrist on repeated excitations of the cortex cerebri.

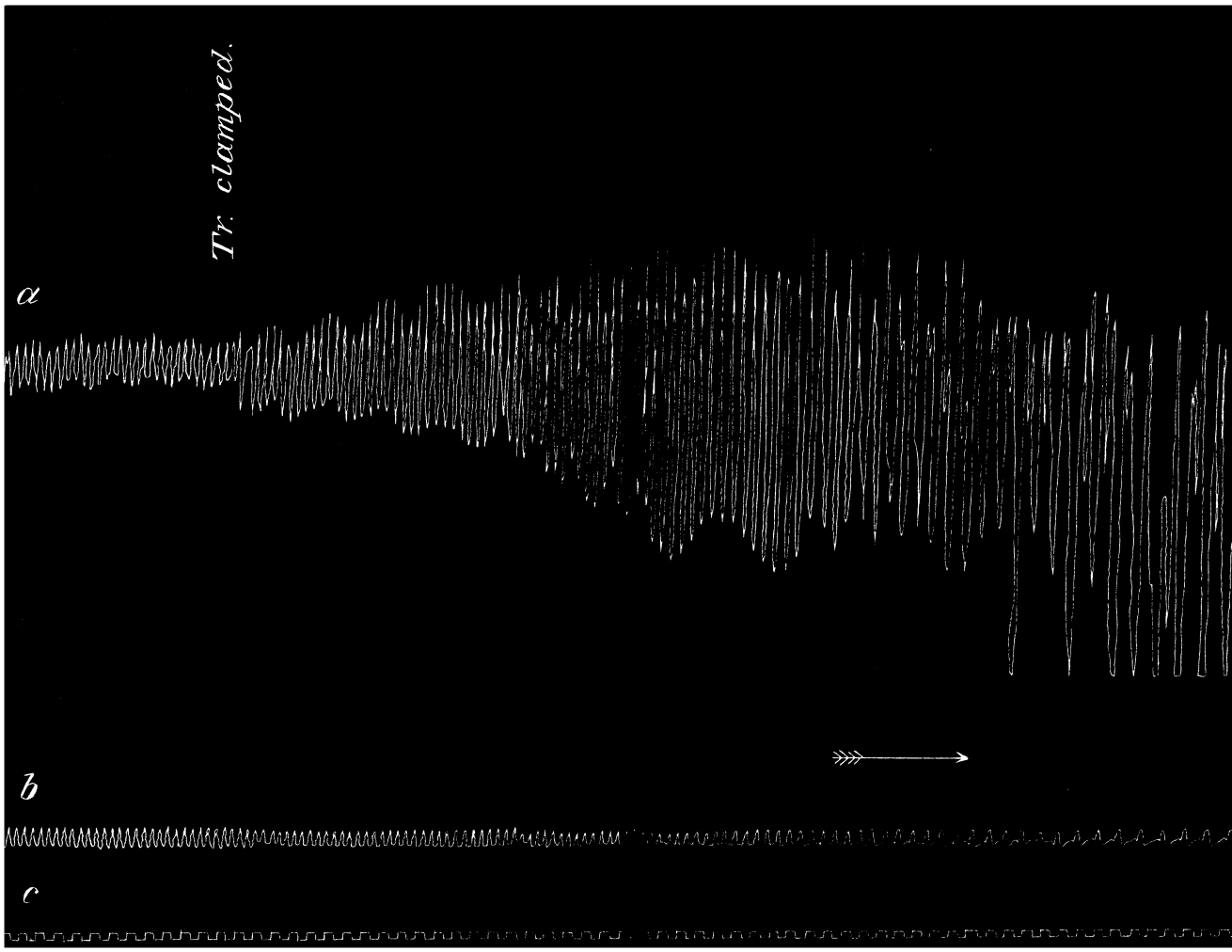
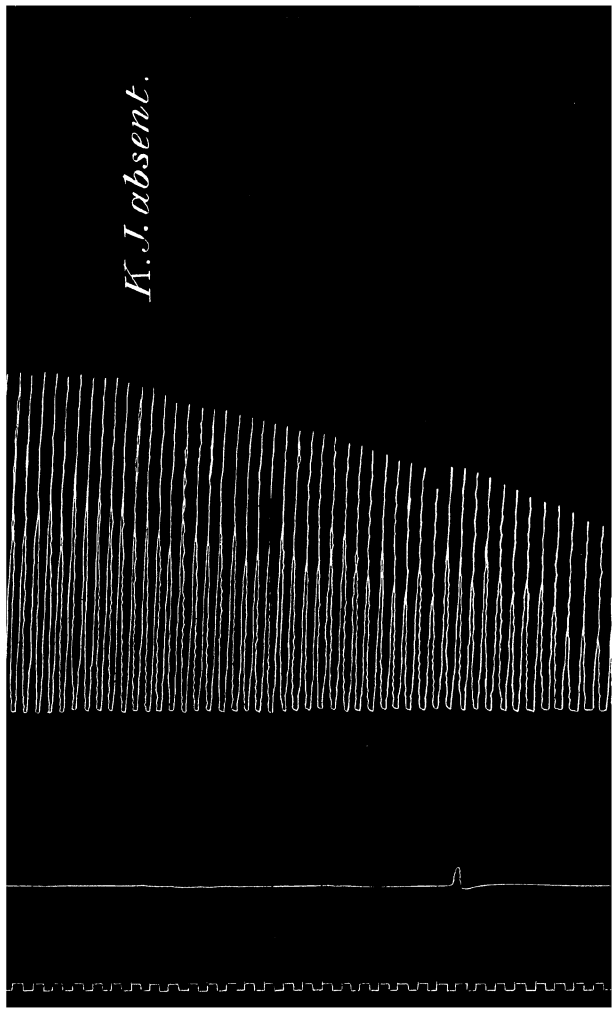
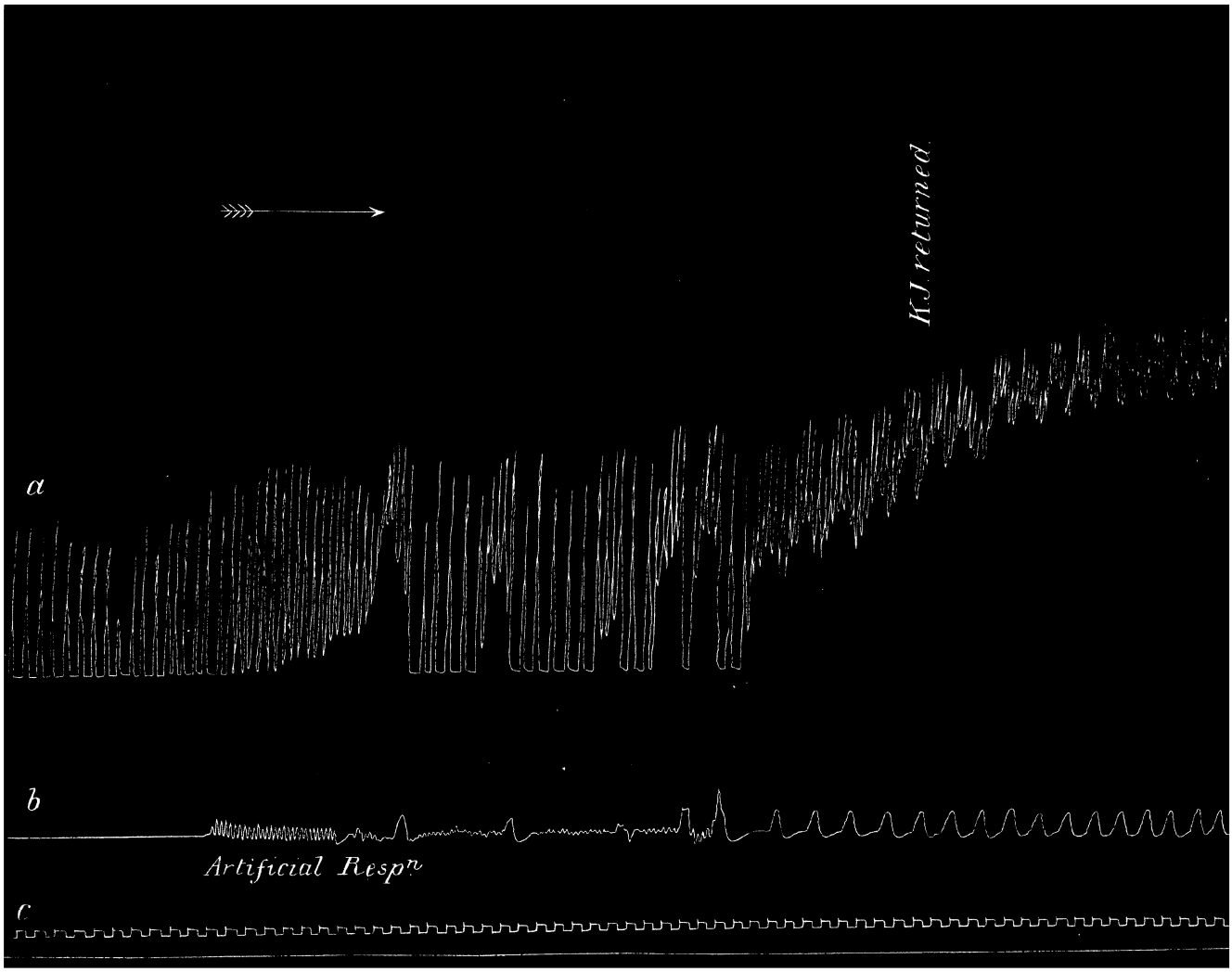

Tr. clamped.
a
b
c

FIG. 1.


K. I. absent.

Russell.

FIG. 2.



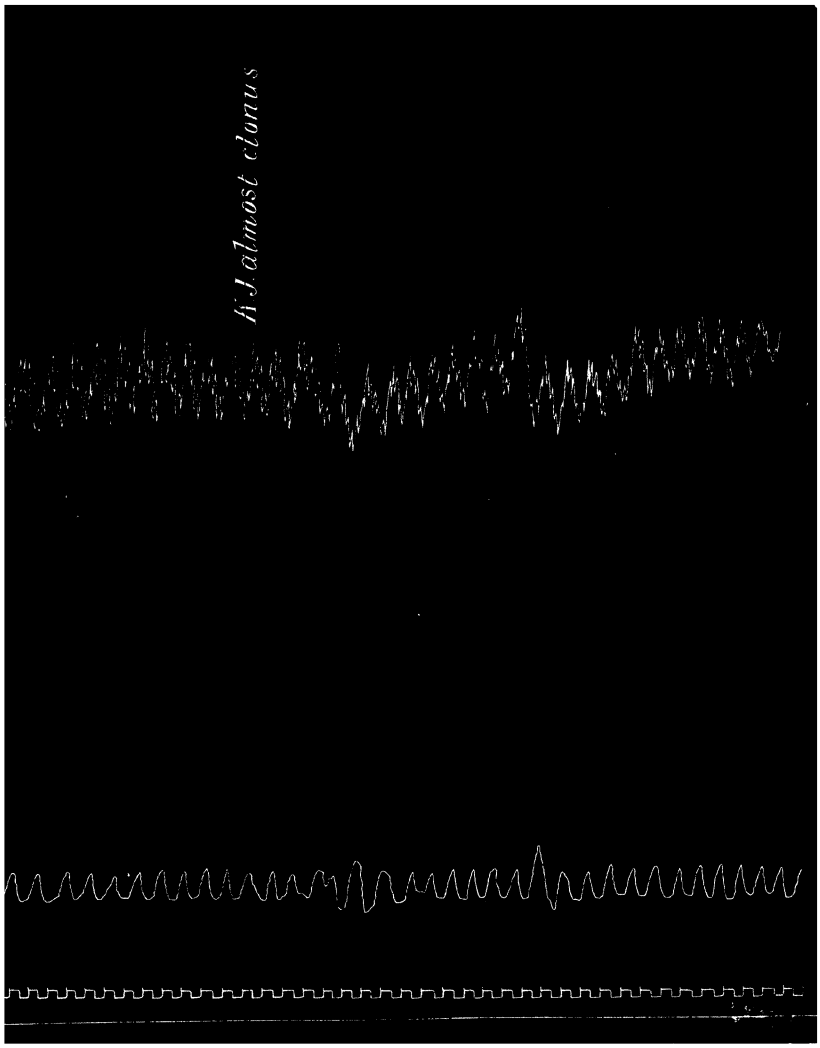
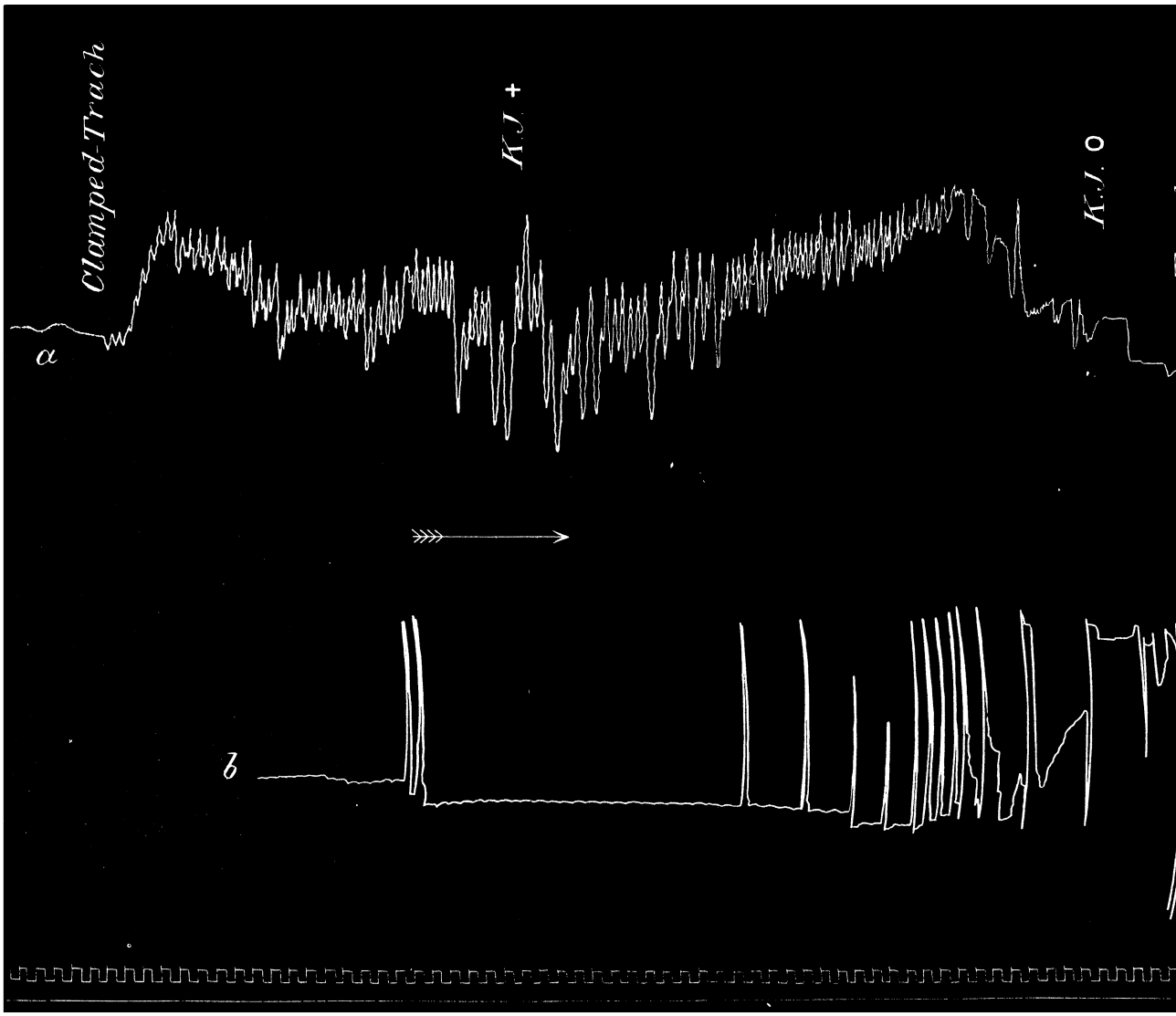

A J almost clonus

FIG. 3.



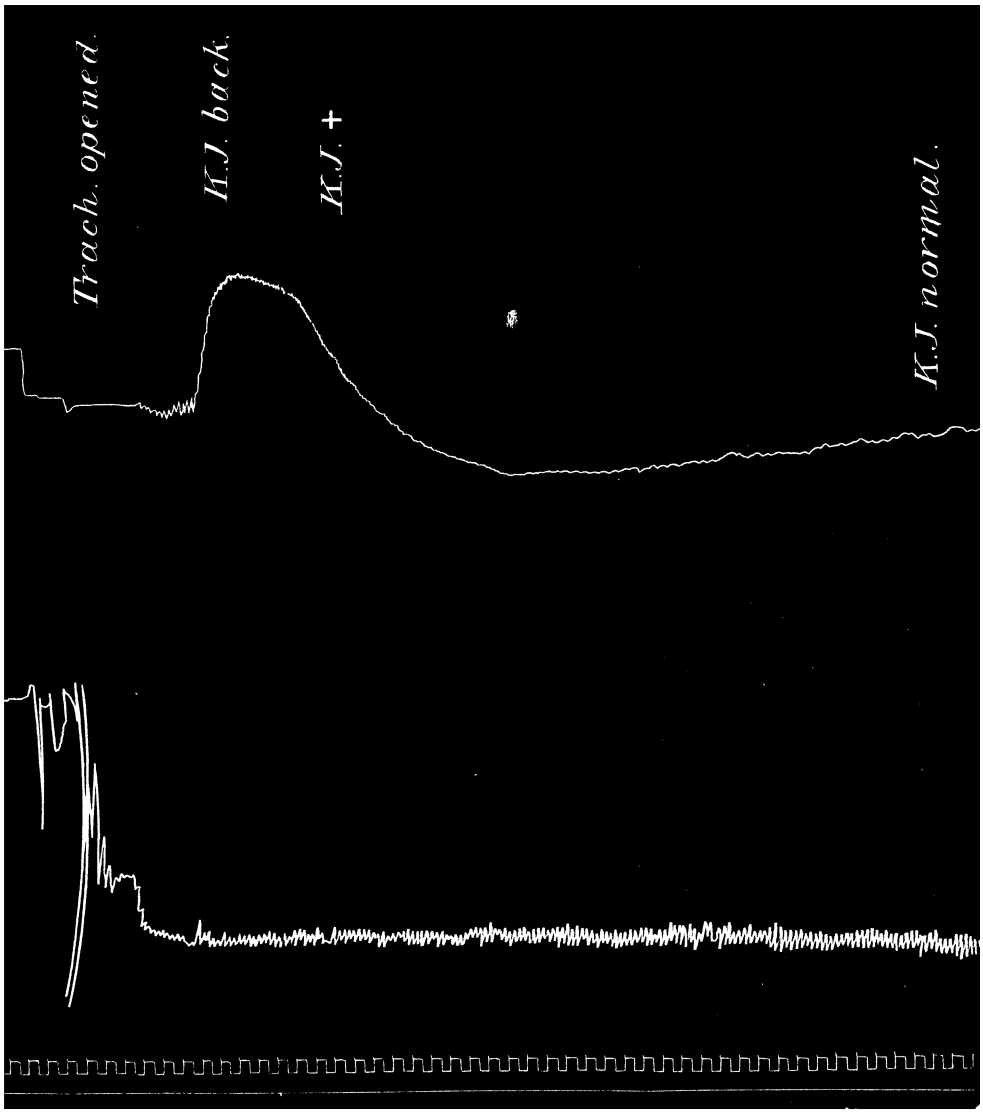

Trach. opened.
K.J. back.
K.J. +
K.J. normal.

Fig. 4.

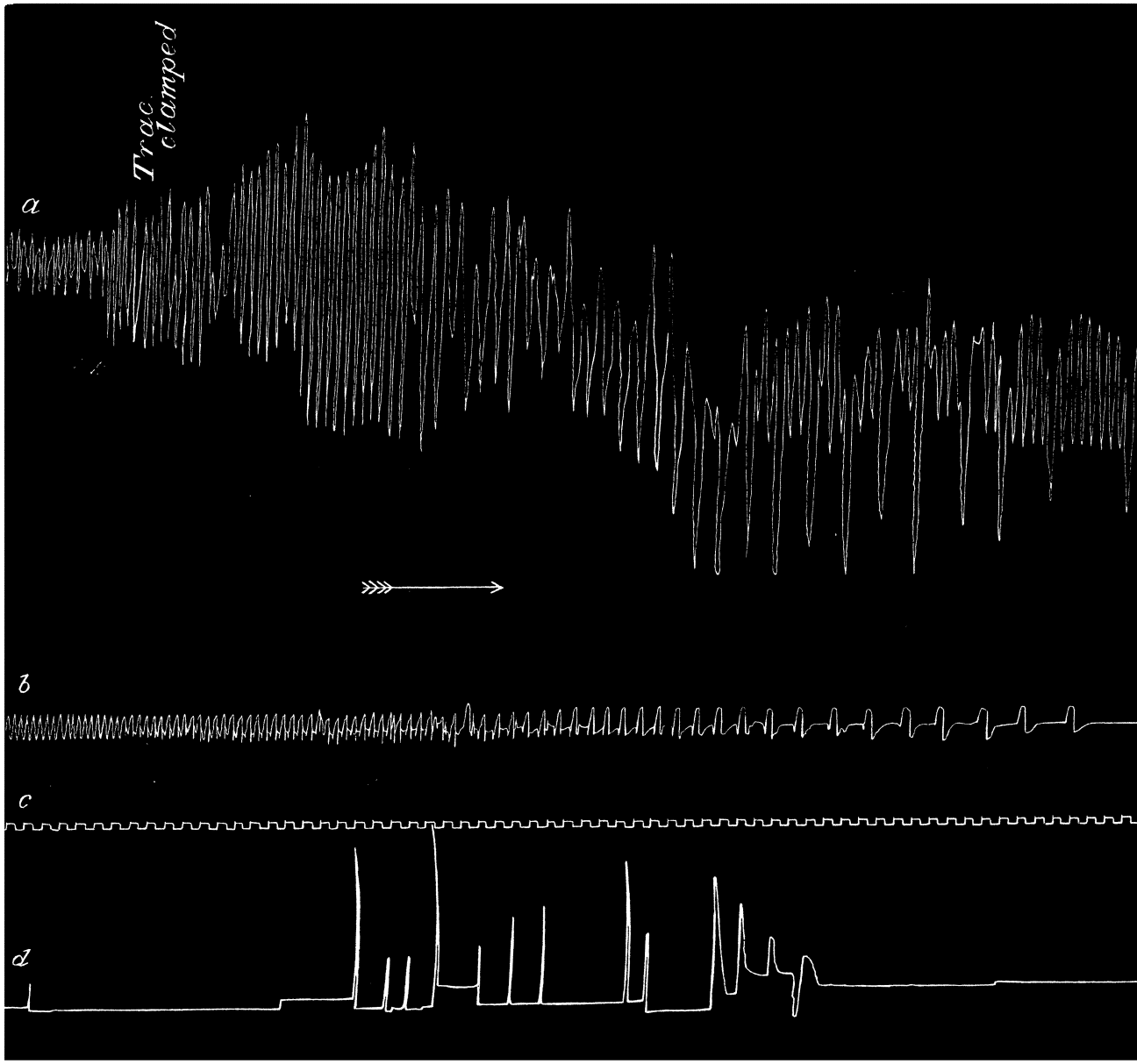


FIG. 4.

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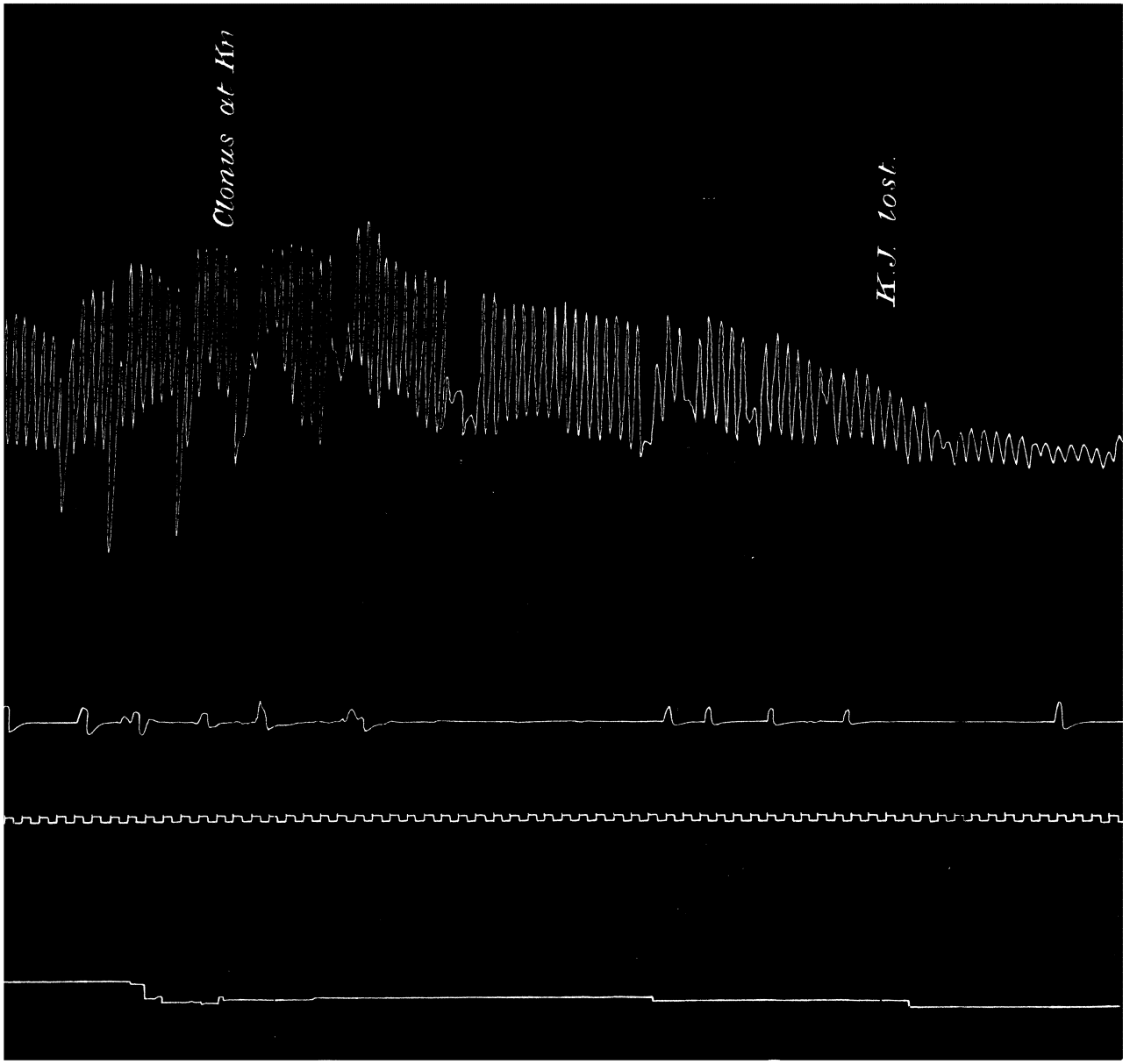
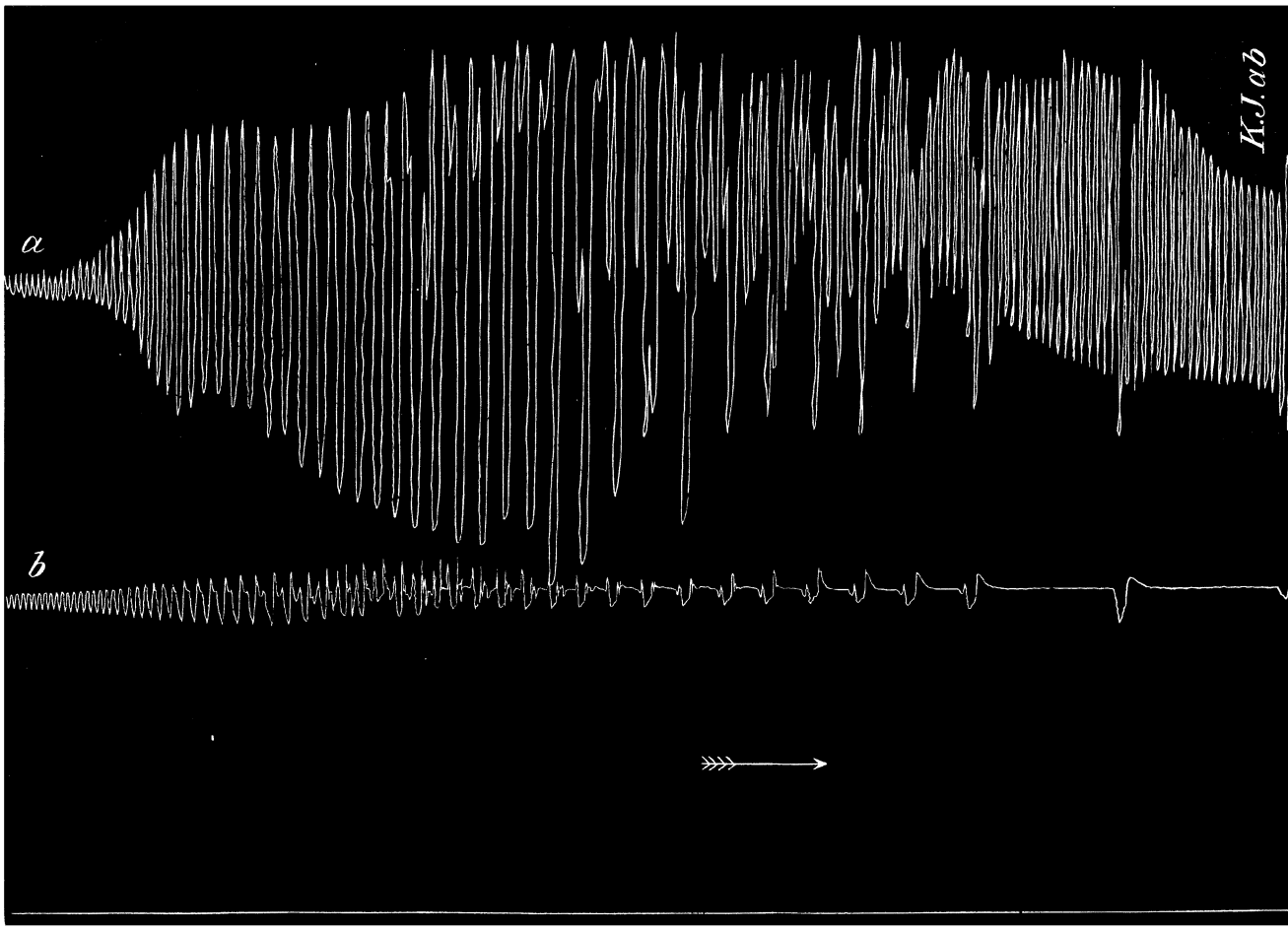
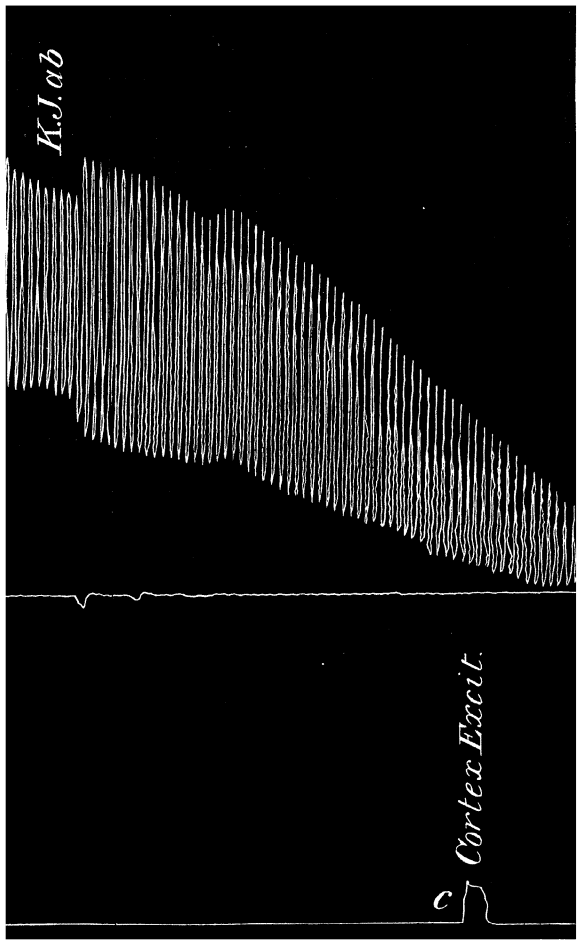
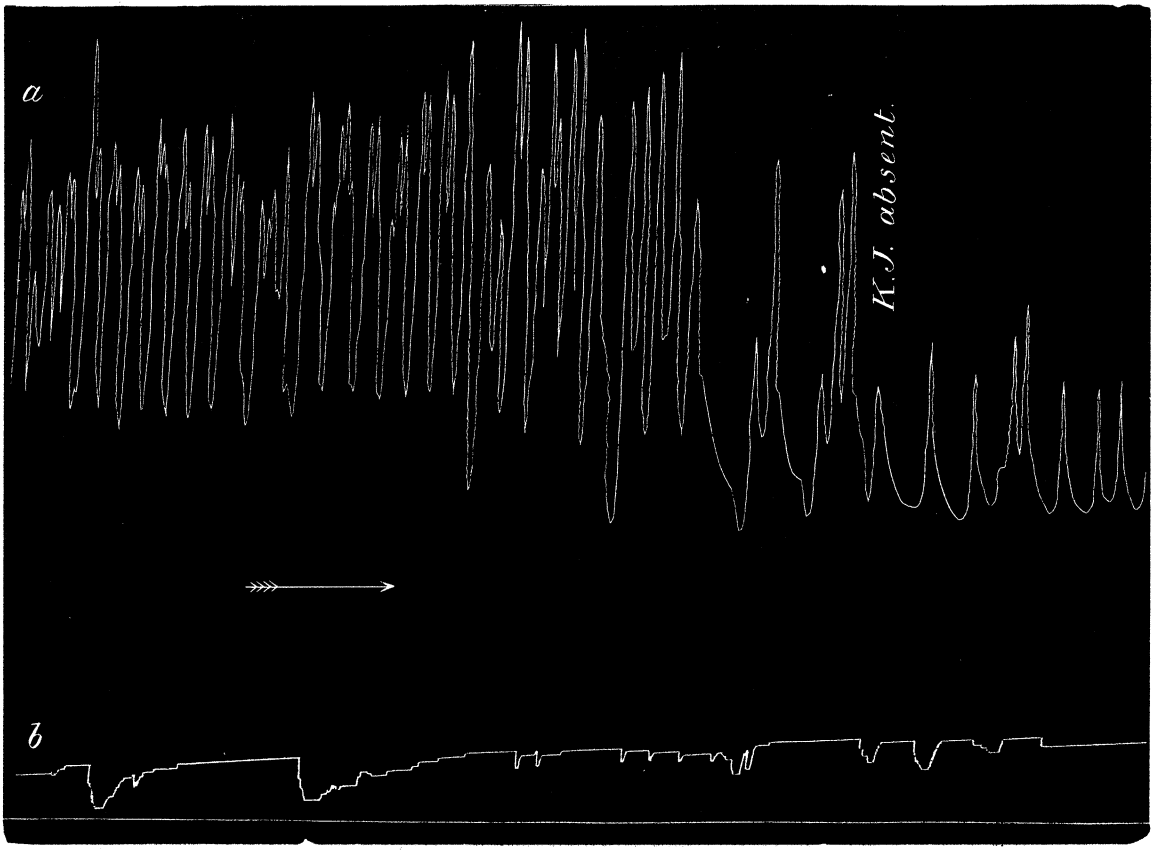
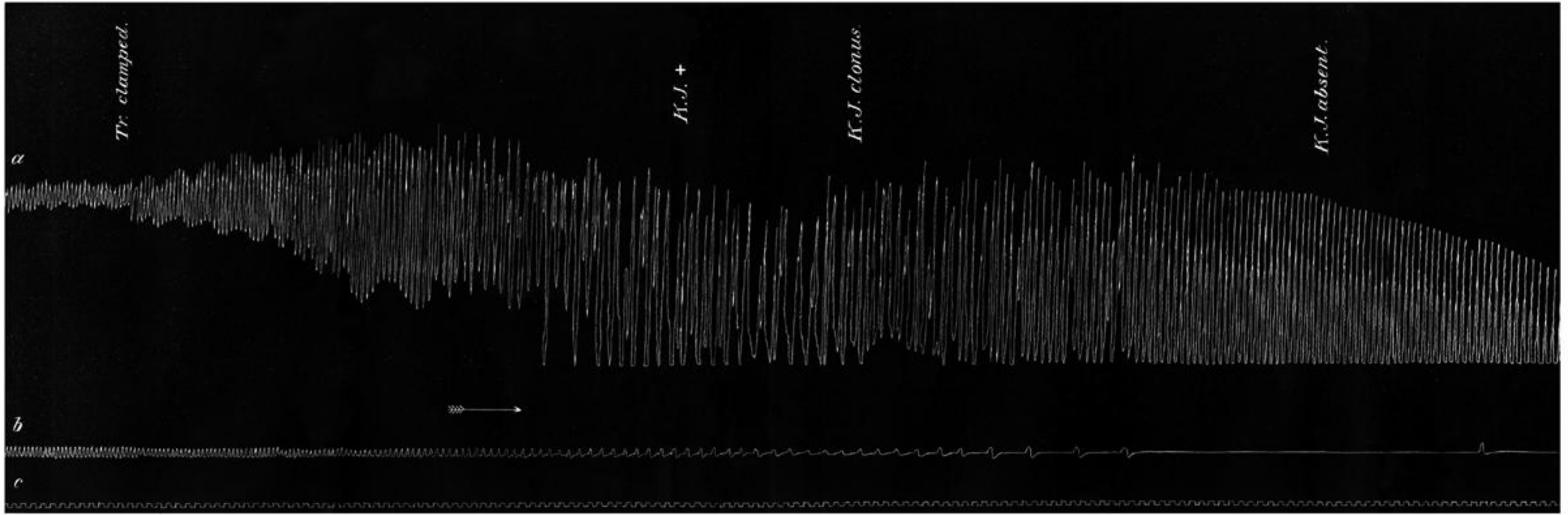


FIG. 5.




K.J. ab
c
Cortex Excit.


a
K.J. absent.
b


Tr. clamped.
K.J. +
K.J. clonus.
K.J. absent.
a
b
c

Russell.

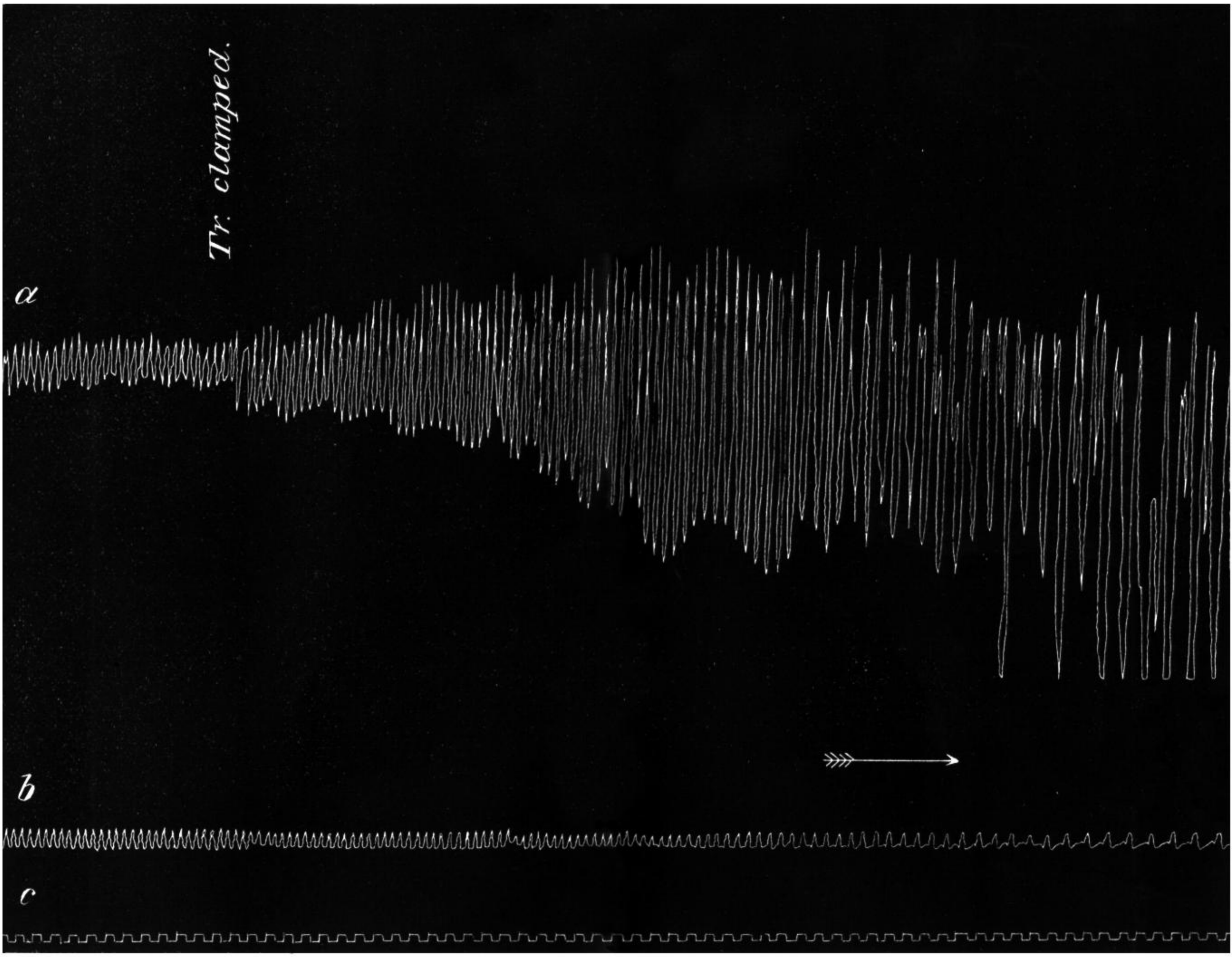
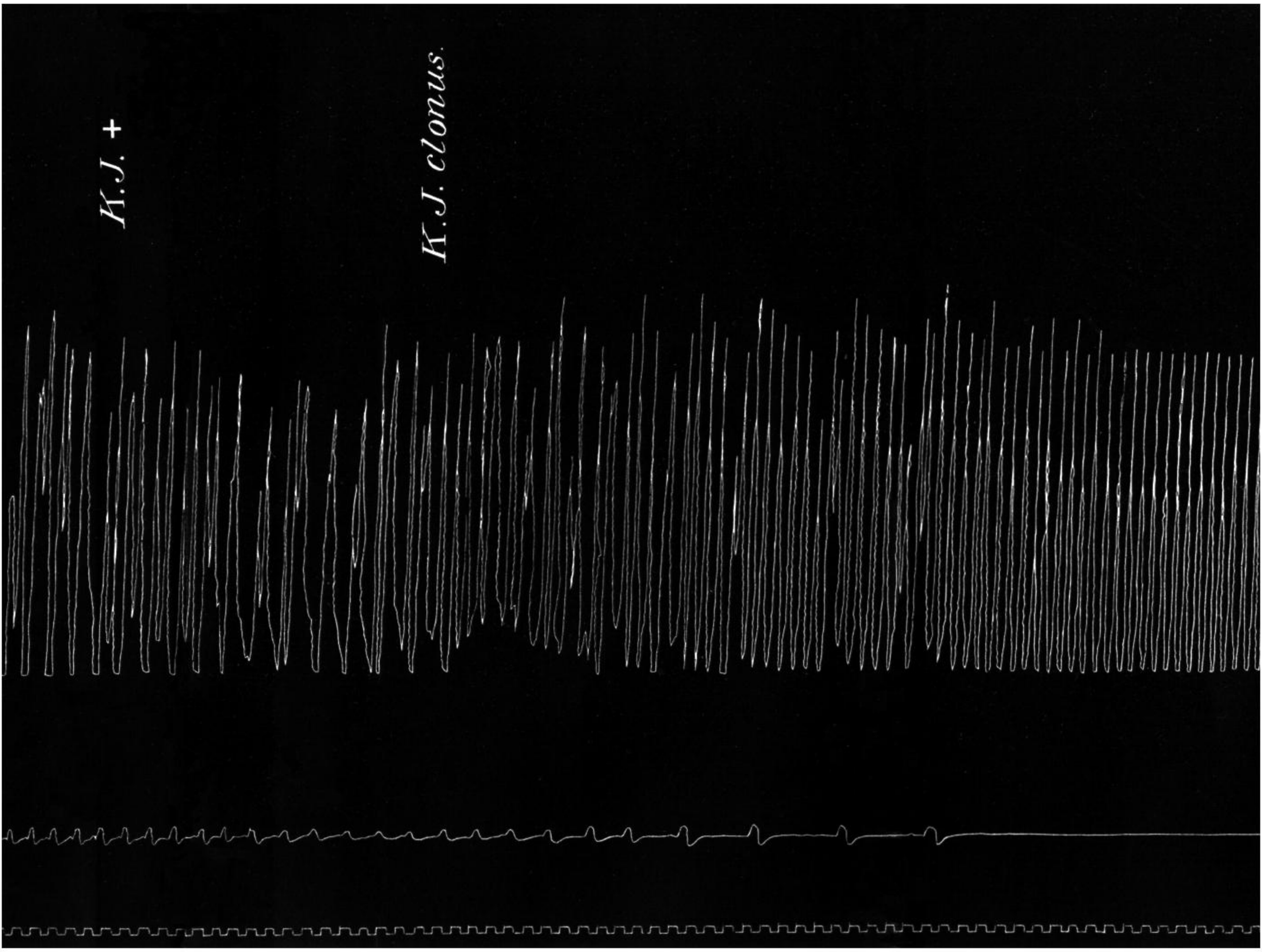
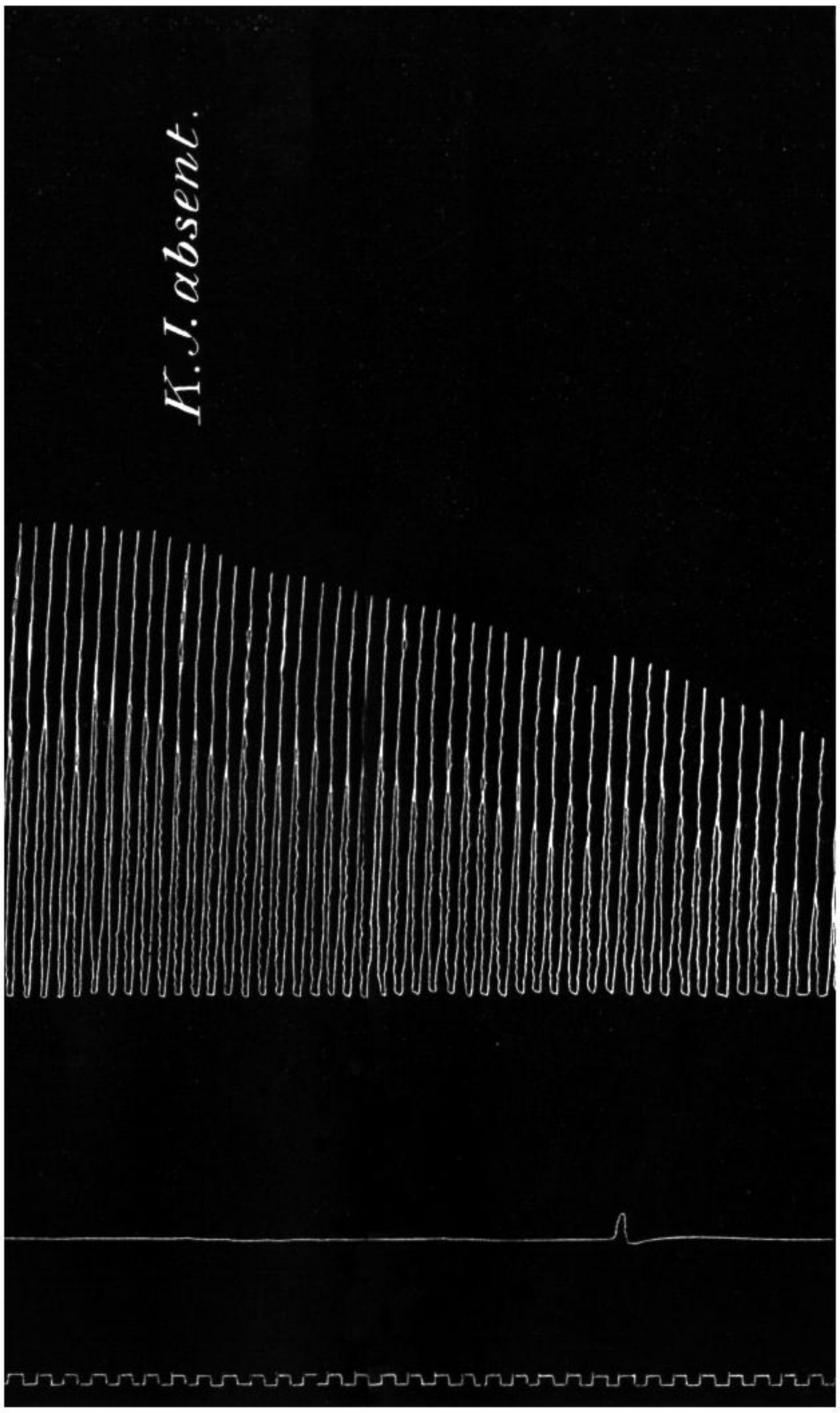
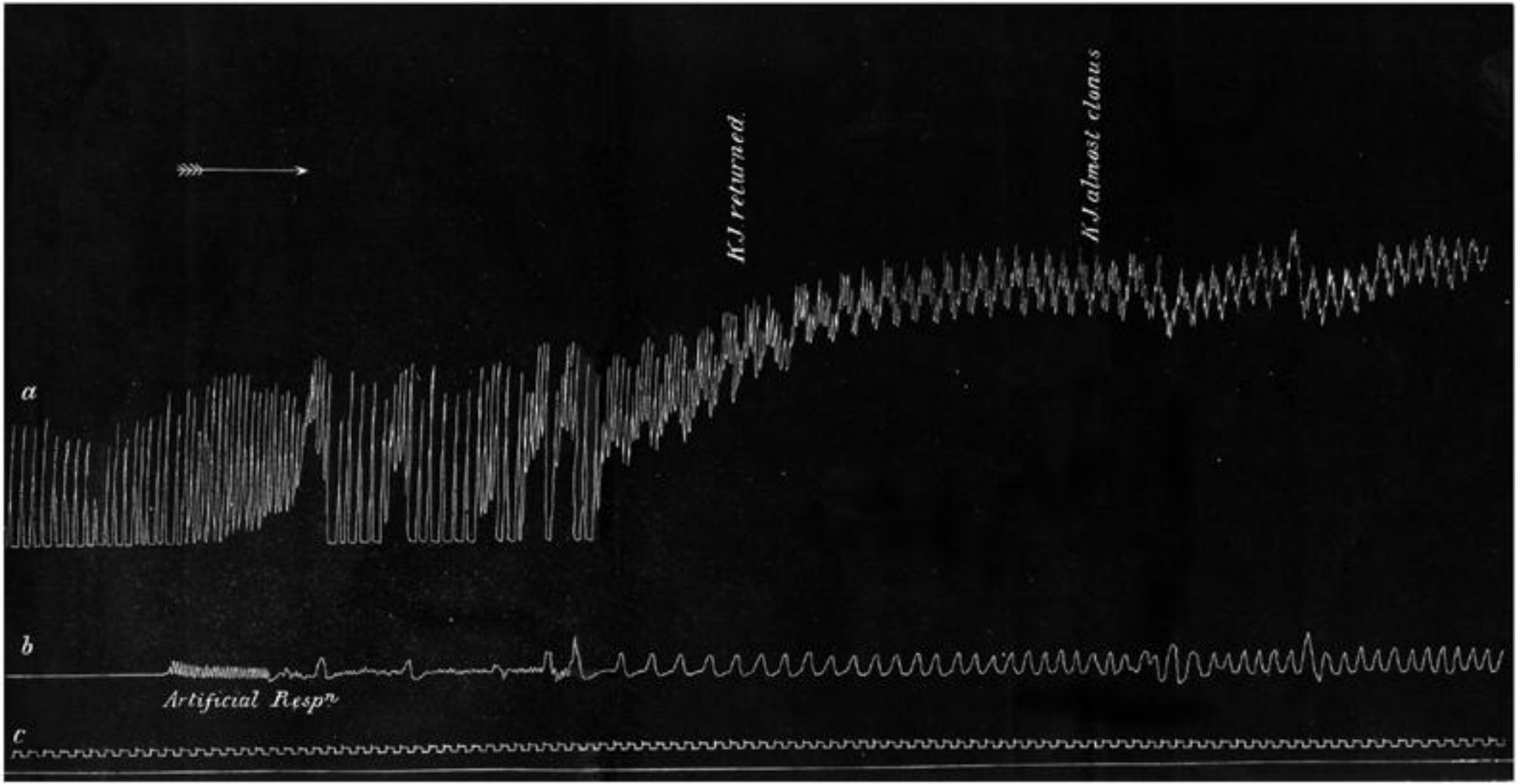


FIG. 1.

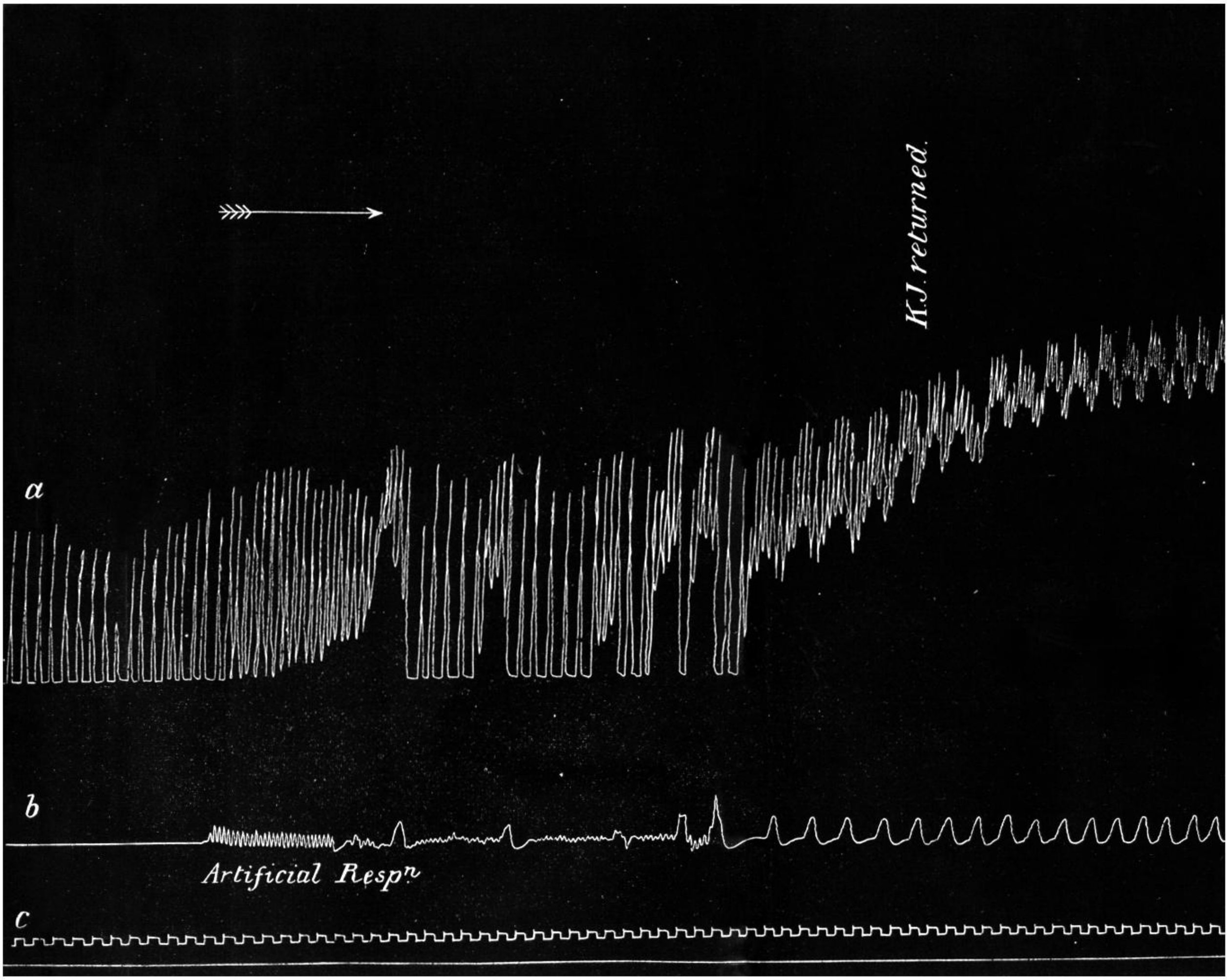


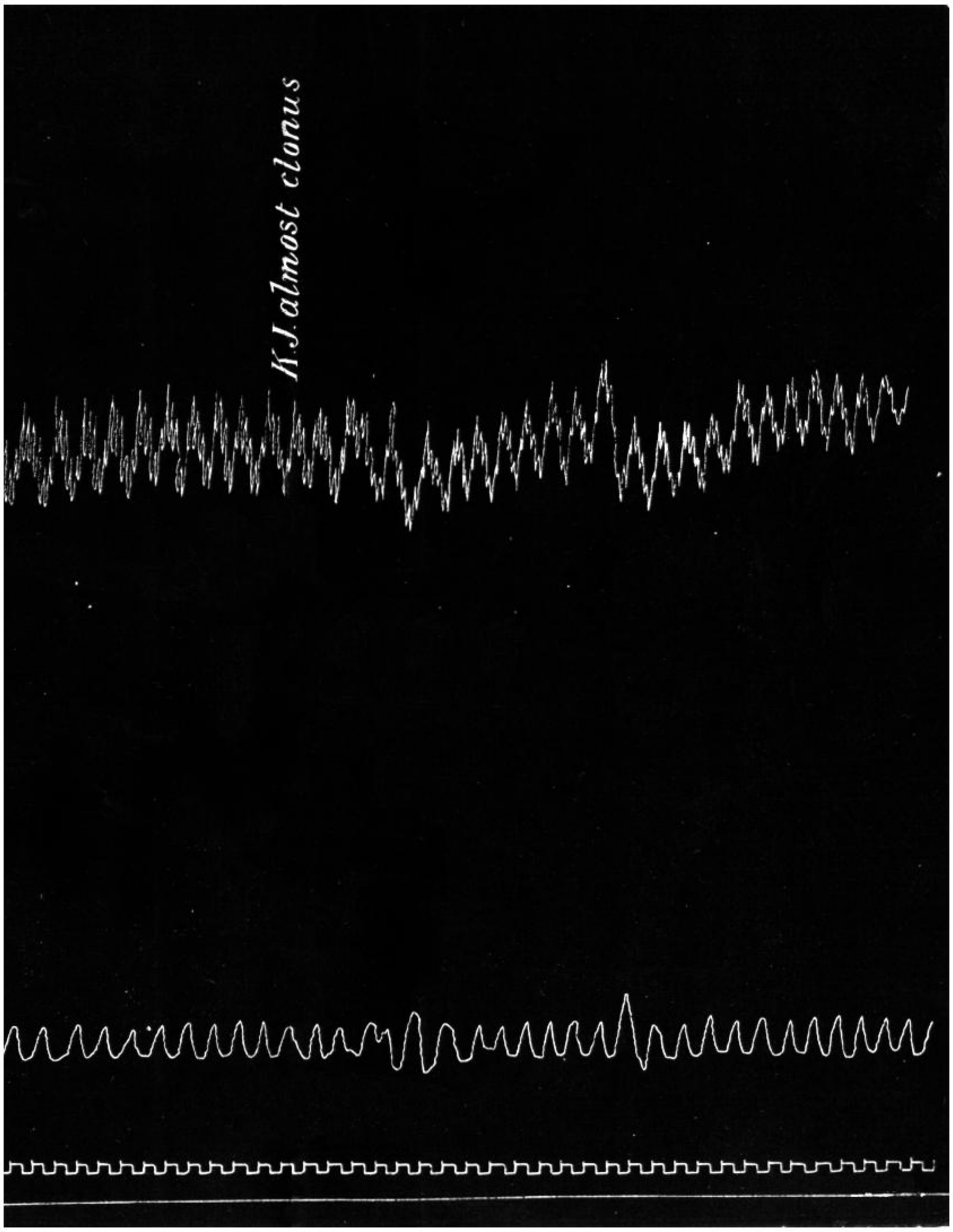

K. J. absent.

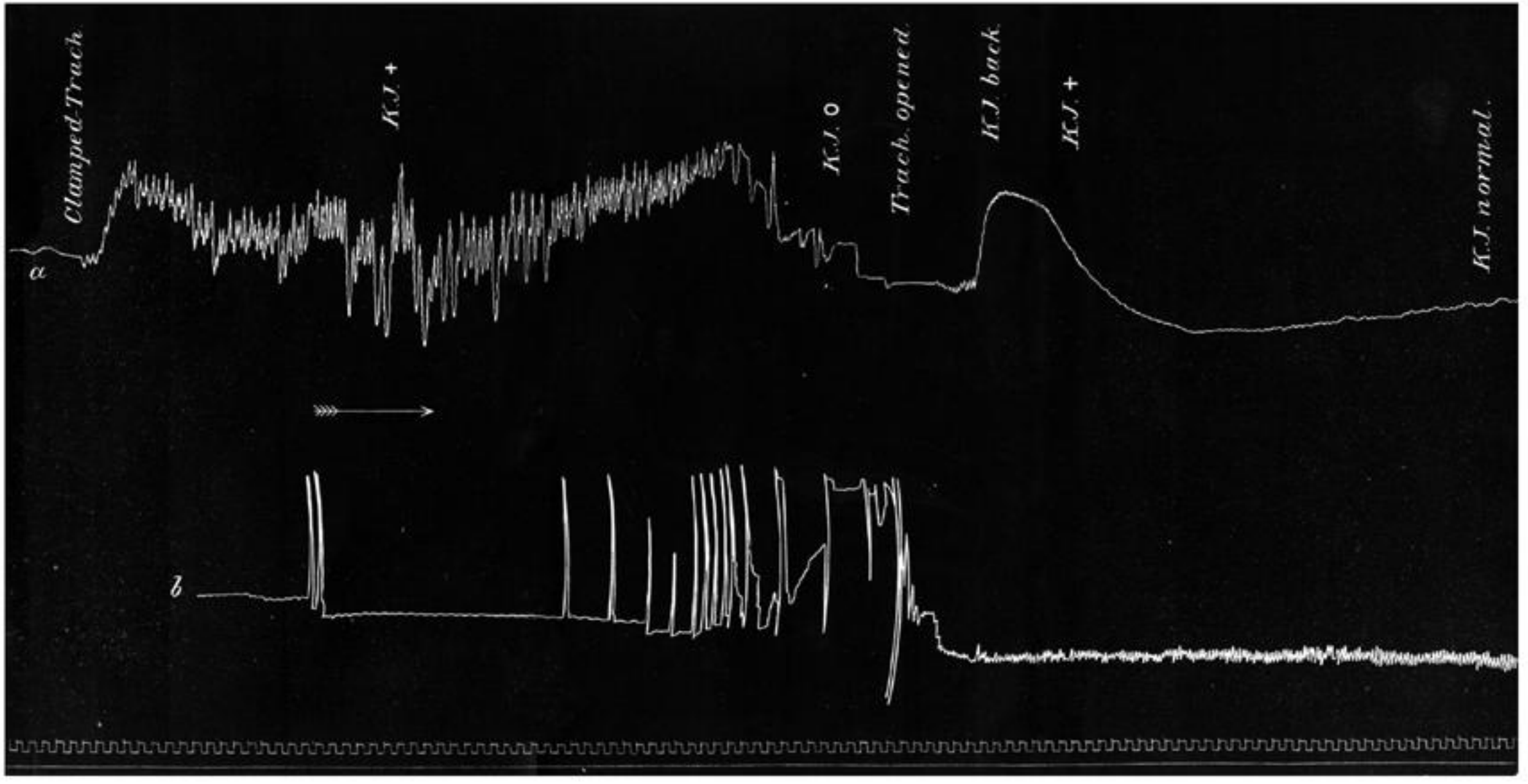

K.J returned.
K.J almost clonus
a
b
Artificial Respn
c

Russell.

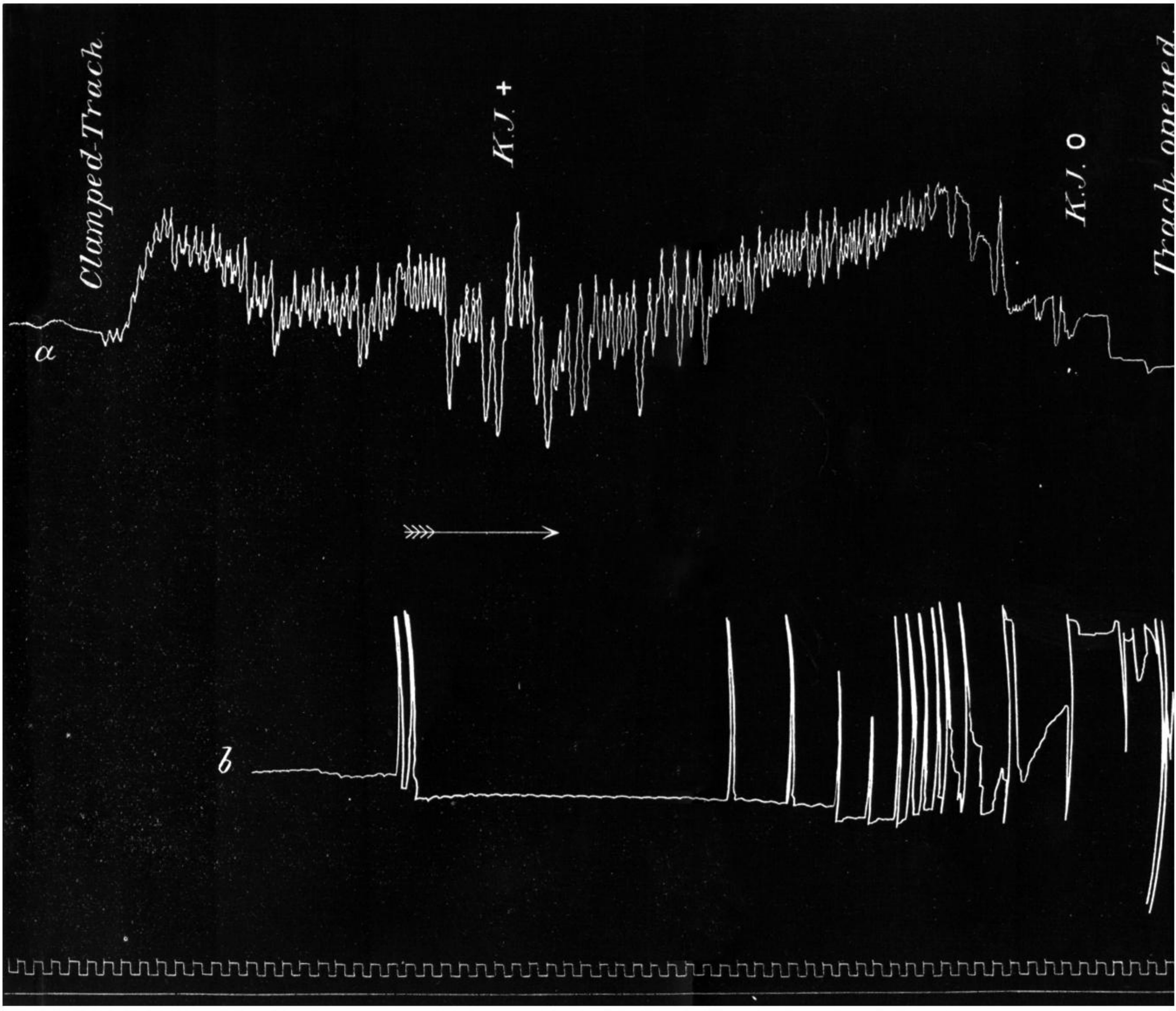
FIG. 2.

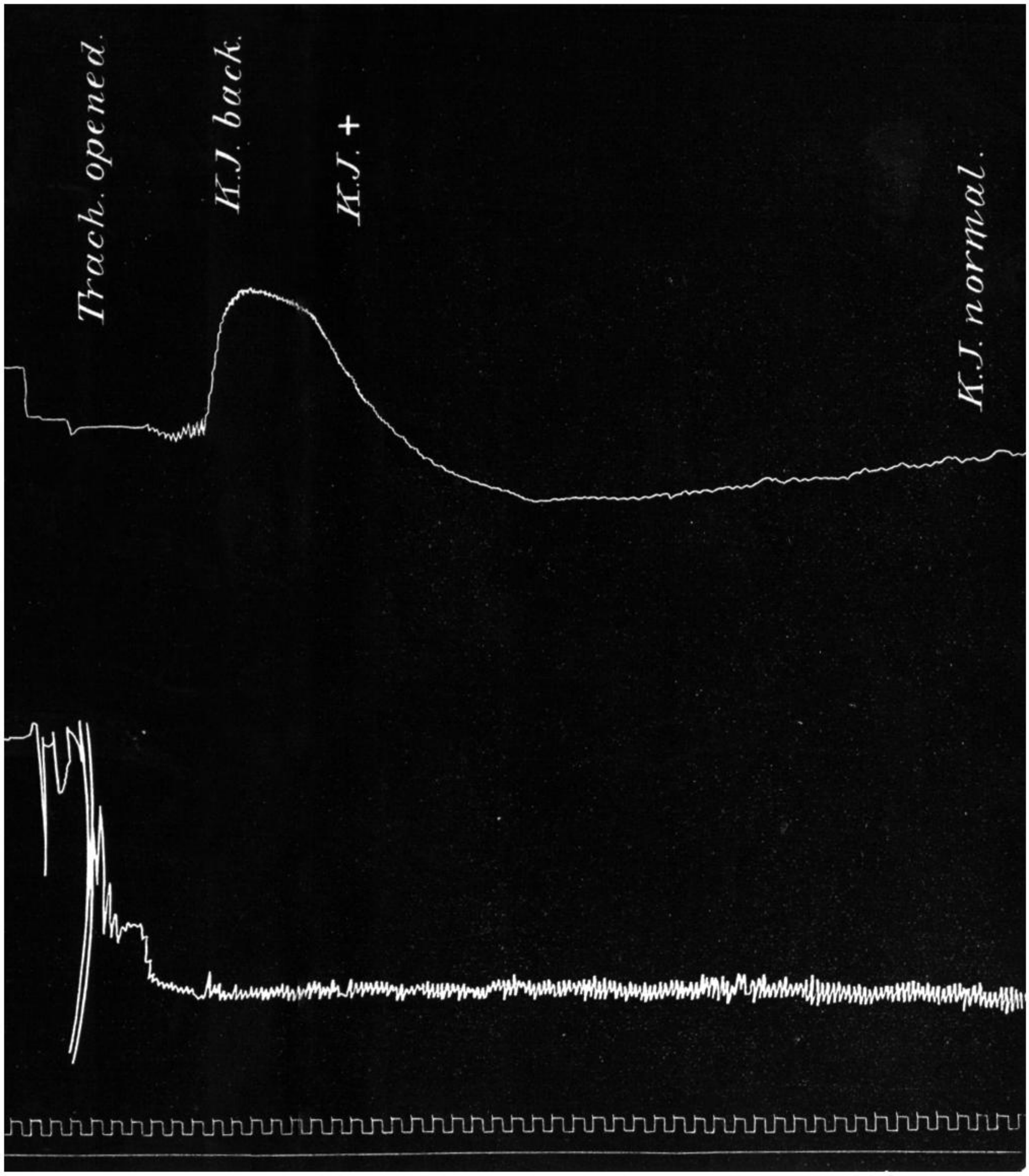



K.J. almost clonus


Clamped-Trach.
K.J. +
K.J. 0
Trach. opened.
K.J. back.
K.J. +
K.J. normal.
a
b

Russell. FIG. 3.




Trach. opened.
K.J. back.
K.J. +
K.J. normal.

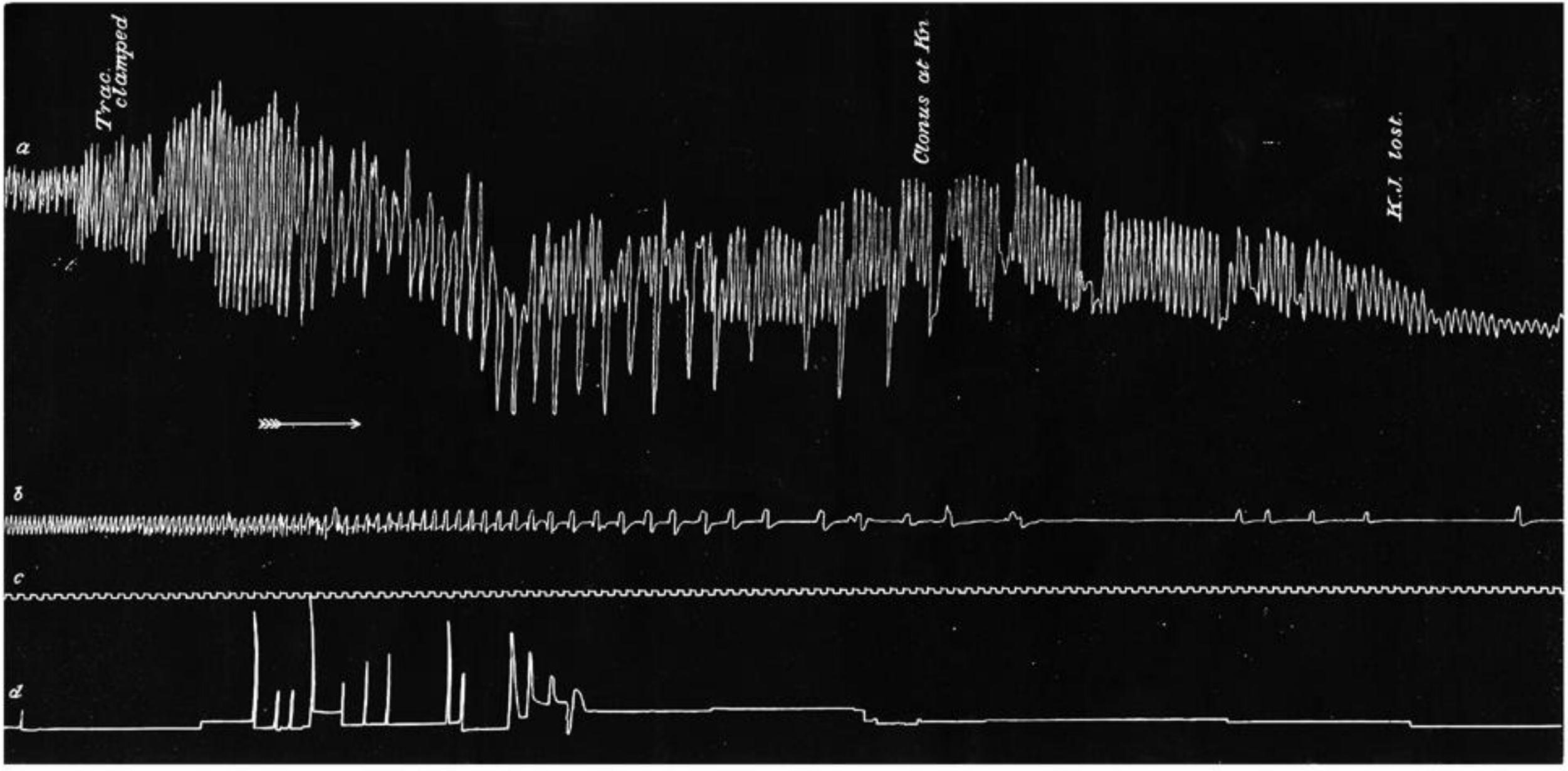

Trac. clamped
Clonus at Kn
K.J. lost.
a
b
c
d

FIG. 4.

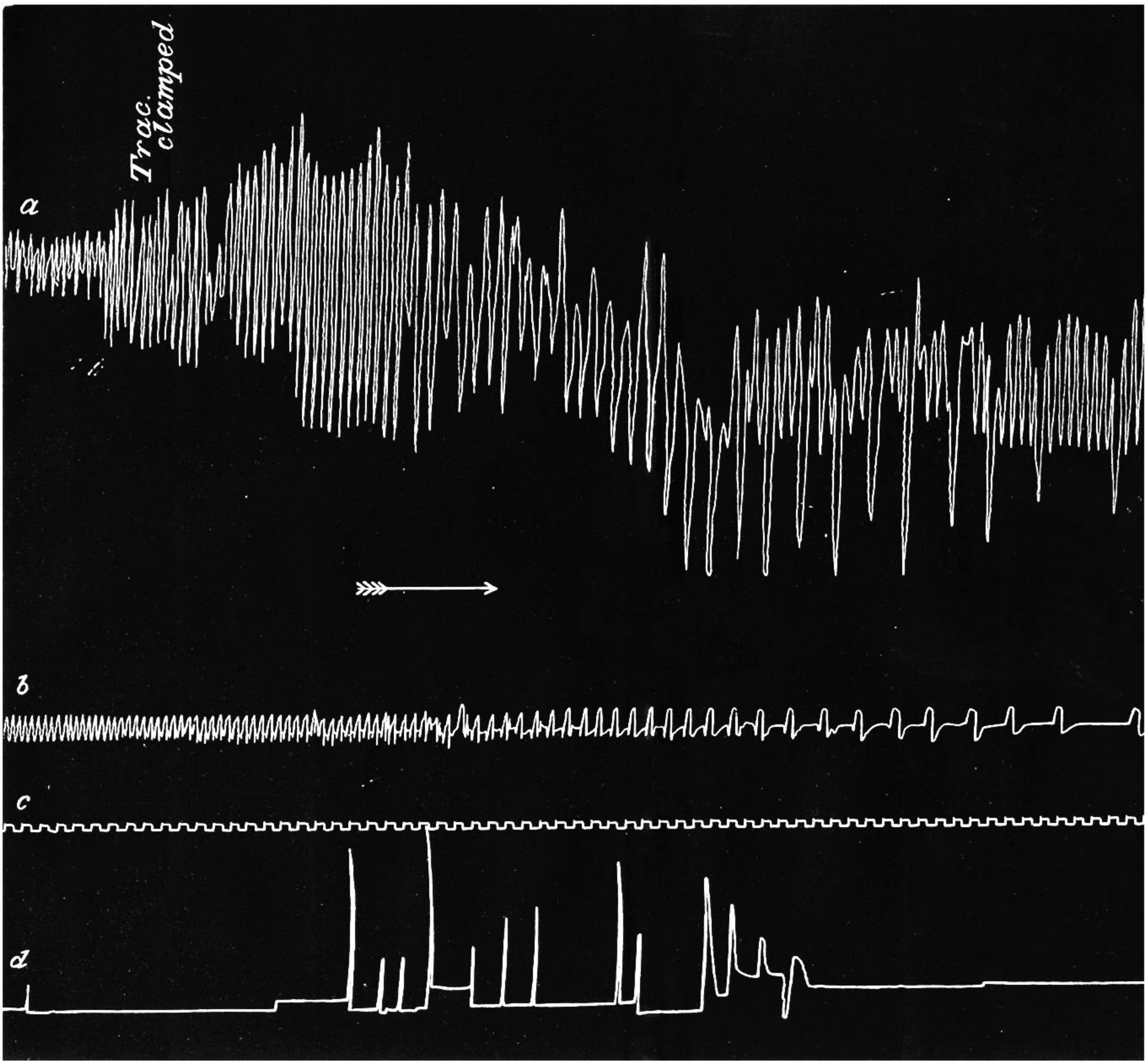


FIG. 4.

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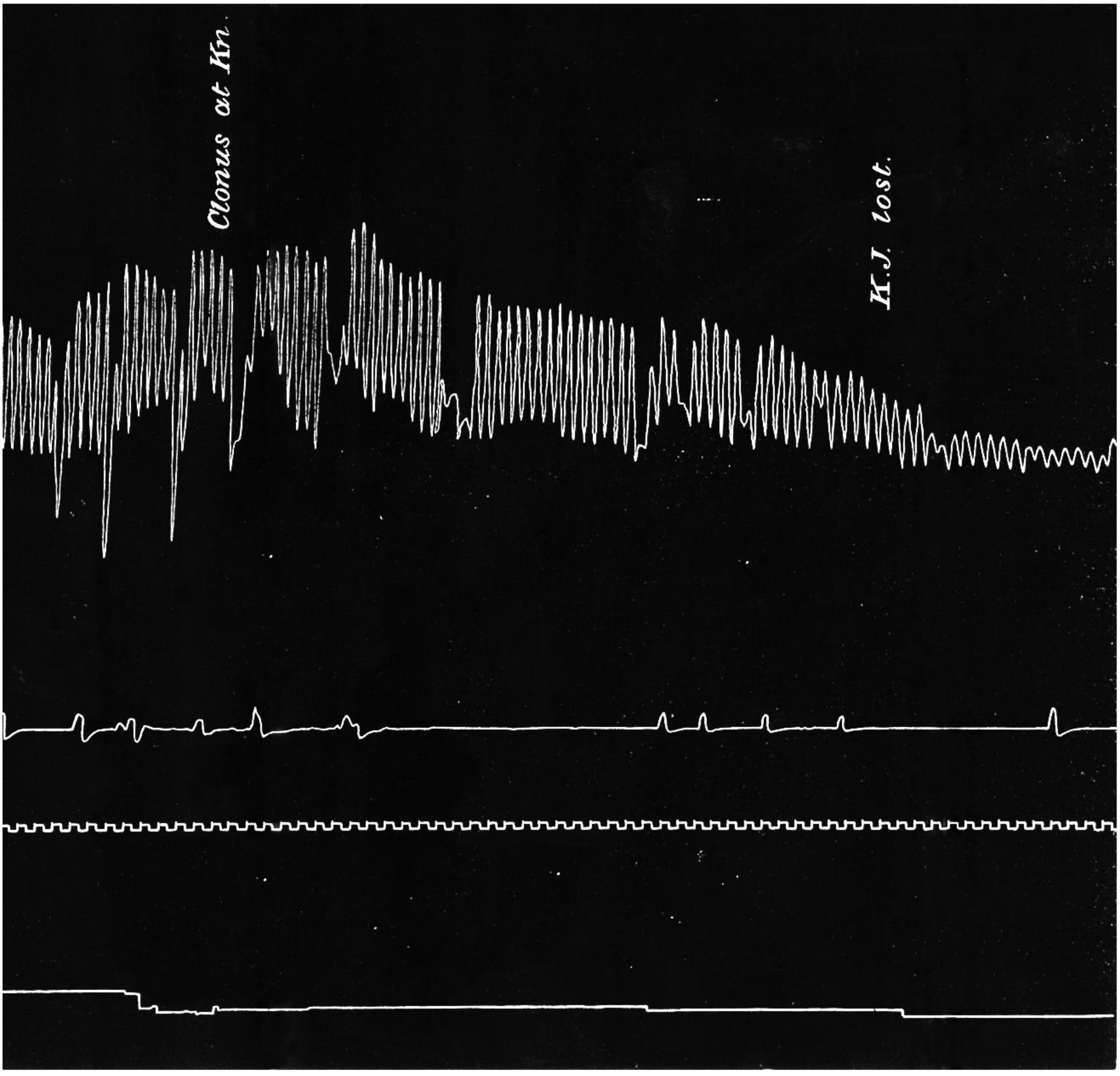
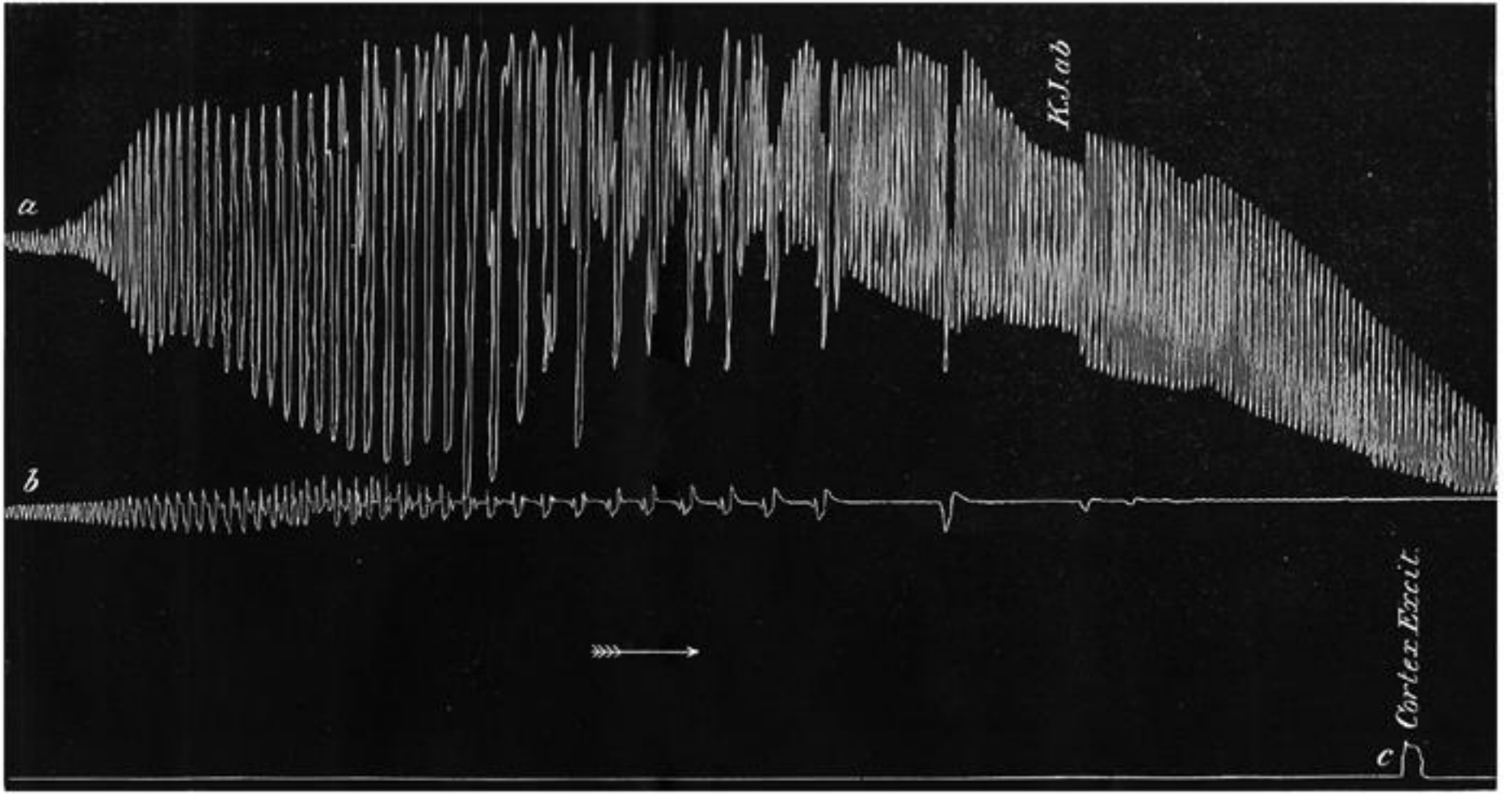
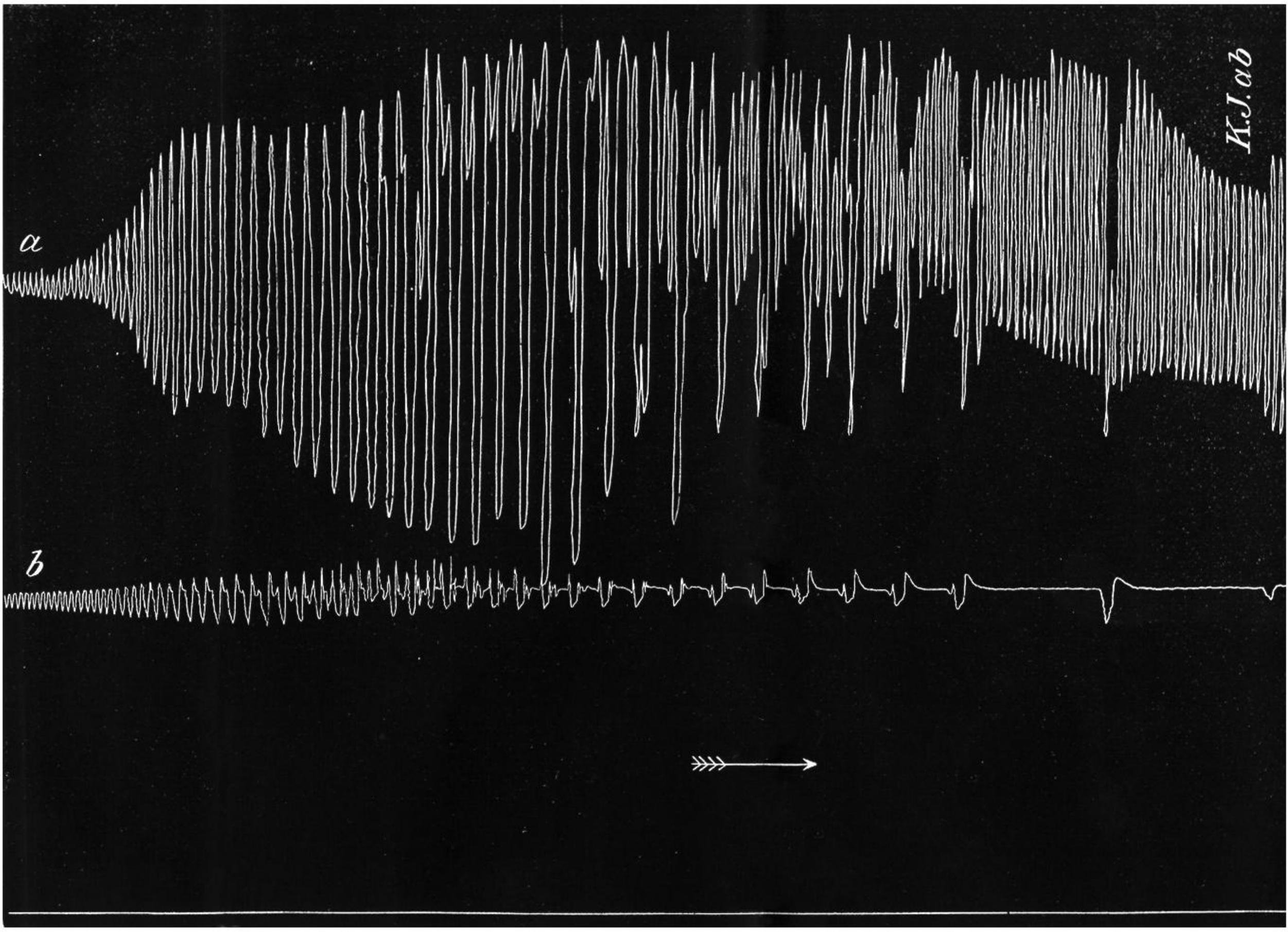



K.J. ab
a
b
Cortex Excit.
c

Russell.

FIG. 5.



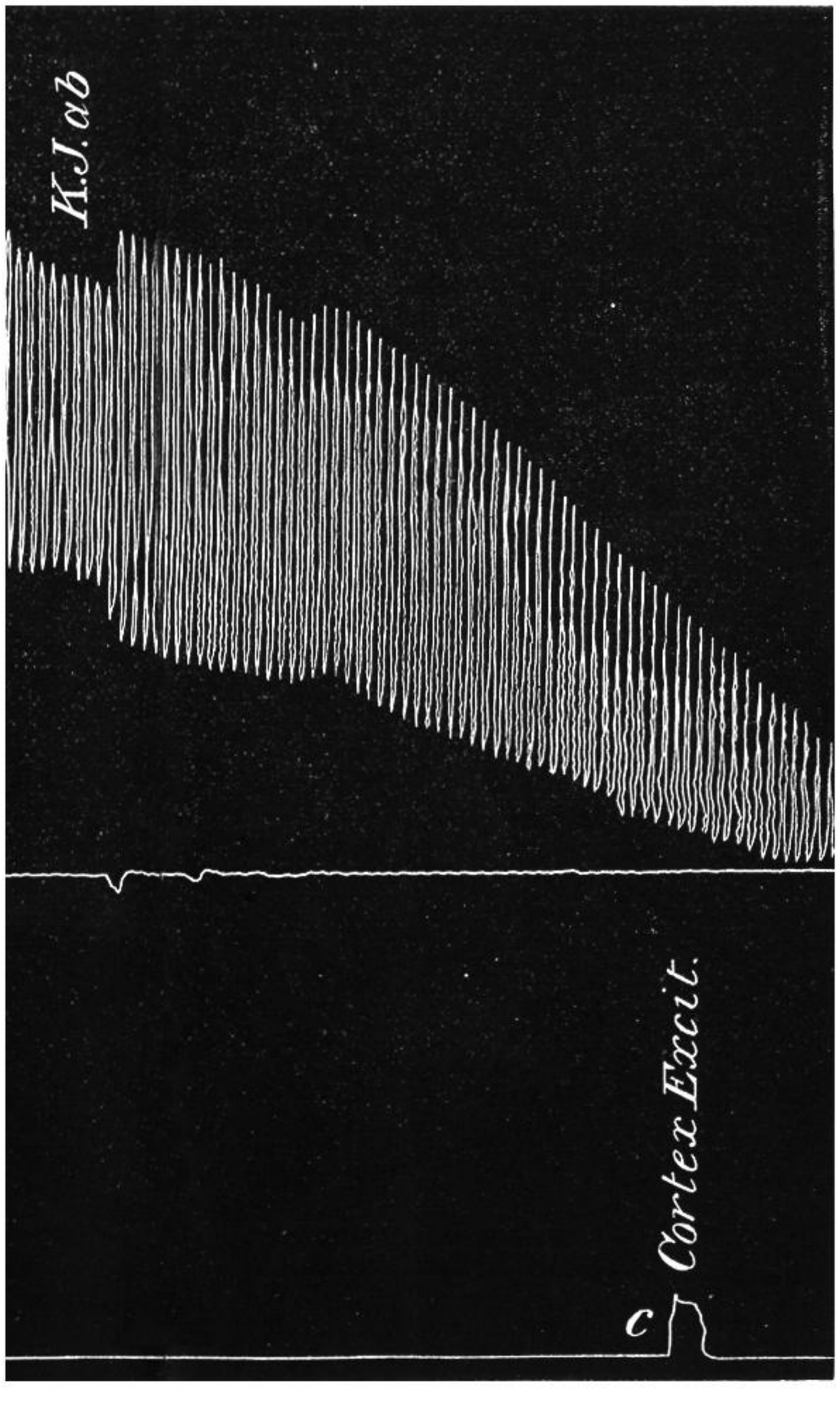

K.J. ab
c
Cortex Excit.

FIG. 6.